2009年國科會伯樂計畫

主辦單位：行政院國家科學委員會
執行單位：財團法人國家實驗研究院

37 years of R&D :
From Dynamic Plasticity and Impact Engineering
to
Synergy of Engineering Science with Nature

37年的研發**:** 由 動態塑性力學 和 撞擊工程學
延伸至 工程科學 與 大自然的互應作用

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GIS “Dynamics of Materials and Structures
In Severe Environment”

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GIS "Dynamics of Materials and Structures In Severe Environment"

1. – Introduction (1)

➔ **Throughout 37-years of professional career :**

World Events → generated interesting and challenging problems to R&D in Impact Engineering

➔ **Post-World War II :**

Cold War Era → yielded incentives to develop :
- Defense Equipments & Systems
- New technologies of production and advanced processes.

People of Western Countries →
- took benefits of Economic prosperity and expansion
- claimed for new products, comfort and safety
- generated a Society of Consumption and also a System of Markets Economy.

1. – Introduction (2)

Markets and Products Competition

Weapons and Space Competition

Both required Expansion of

Sciences Bases Boundaries

Impact Engineering Boundaries

For example :

World events such as :

(1) - Missile defense in the early 1970s,

(2) - the Energy crisis started later in the decade,

(3) - the armor/anti-armor initiative in the 1990s

required advances in :

From the 1960s Continuum mechanics approaches to recent stage of :

Plasticity Theory

Fracture Science

Dynamic Plasticity

Dynamic Fracture

Microstructures and multi-scales approaches : Macro-Meso-Micro-Nano

1. – Introduction (3)

➔ I feel fortunate to have opportunities to give my contributions to such stimulating R&D programs during my career

and

to share this chance and these experiences with my highly appreciated colleagues and international partners.

➔ Avoiding to be exhaustive, my presentation in this session will be focused on the retrospective of this area of Research and Development in the past 37 years.

➔ I shall then conclude by describing some examples and speculations of future advances for some topics in the next decades.

2. – Fields of Research and Development in Impact Engineering

A. – Research

1. – Materials behavior under High strain-rate loadings and shock-wave Loadings (Dynamic Plasticity).

2. – Materials behavior under High Loading rates (Dynamic Damage and Dynamic Fracture Science).

3. – Impulse Loading of materials and structures (Crashworthiness).

4. – Modeling of Constitutive equations.

5. – Advanced and new materials.
Bio-materials for medical prostheses (implants).

6. – Human protection and Safety.

7. – Synergy between Engineering Sciences and Nature processes (Biomimicking and Duplication of natural processes).

8. – Multi-scale approaches.

B. - Development

1. - Engineering Processes :

1.1. - High Energy Rate Forming (HERF) :

(a) Electromagnetic Forming,
(b) Electro-hydraulic Forming
(c) Explosive Forming and Dynamic Compaction
(d) Exothermal Reaction Synthesis.

1.2. – High speed machining and forming of materials.

2. - Automobiles industries

3. - Aerospace industries

4. - High velocity land and sea transports

6. – Testing and Measurement Equipments and Methodologies.

7. – Diagnostic and Computational tools

Support to

Civilian applications

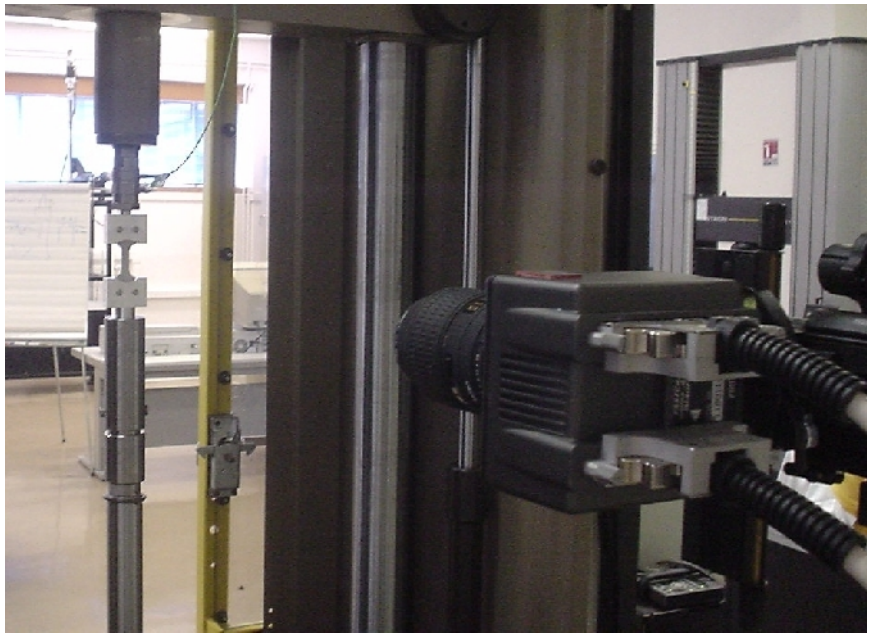
Military applications

2. – An Example of Research and Development in Impact Engineering

A. – Research

1. – Materials behavior under High strain-rate loadings and shock-wave Loadings
(Dynamic Plasticity).

Hydraulic Tensile Testing Machine MTS 810 equipped with a digital high speed camera for strain measurement (Strain-rate range : 1 s^{-1} ~ 200 s^{-1}



B. - Development

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   - 1.1. - High Energy Rate Forming (HERF) :

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   - 1.2. – High speed machining and forming of materials.

2. - Automobiles industries

3. - Aerospace industries

4. - High velocity land and sea transports

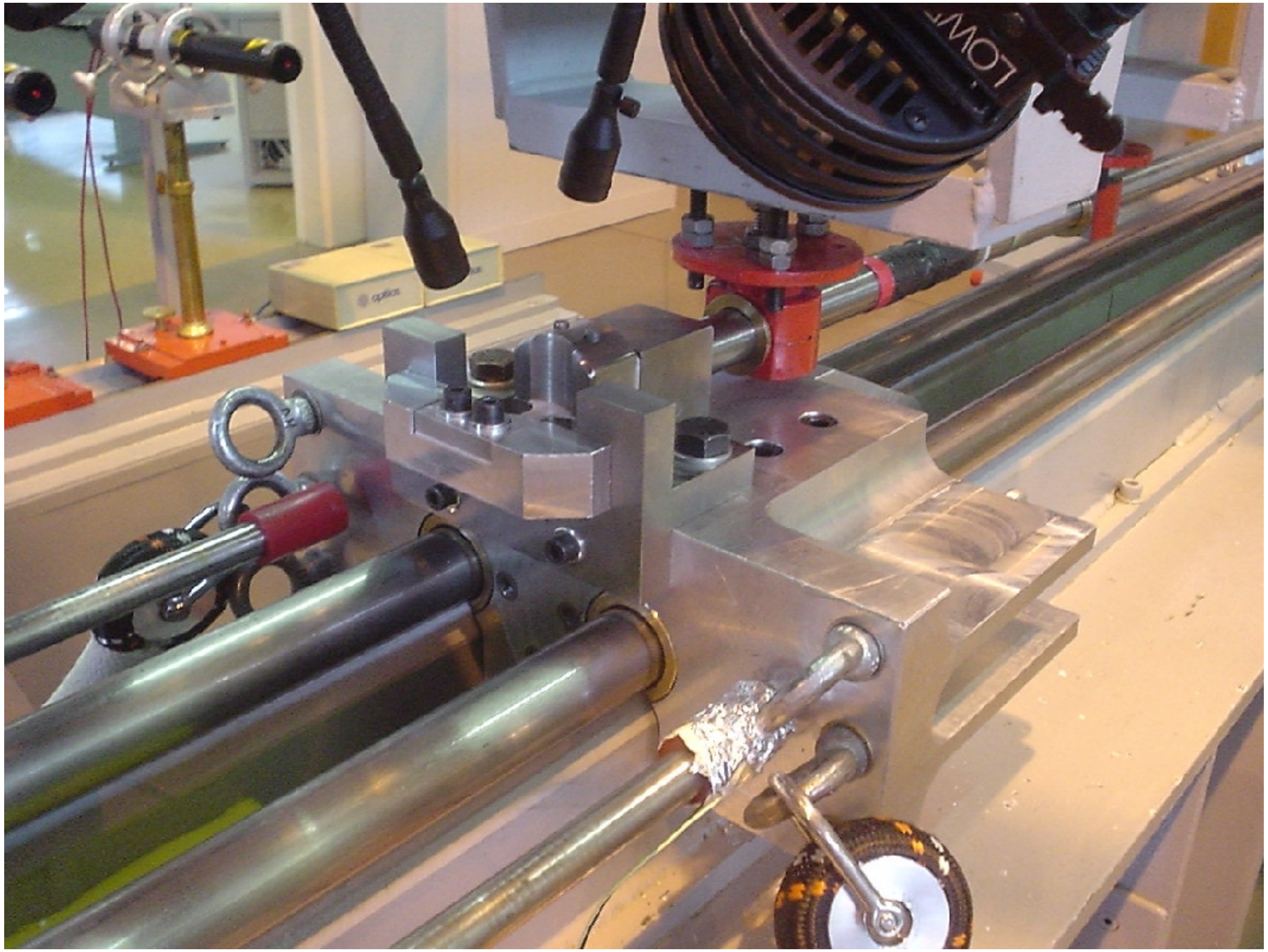
6. – Testing and Measurement Equipments and Methodologies.

7. – Diagnostic and Computational tools

2. – An Example of Research and Development in Impact Engineering

Materials behavior under High strain-rate loadings and shock-wave Loadings (Dynamic Plasticity).

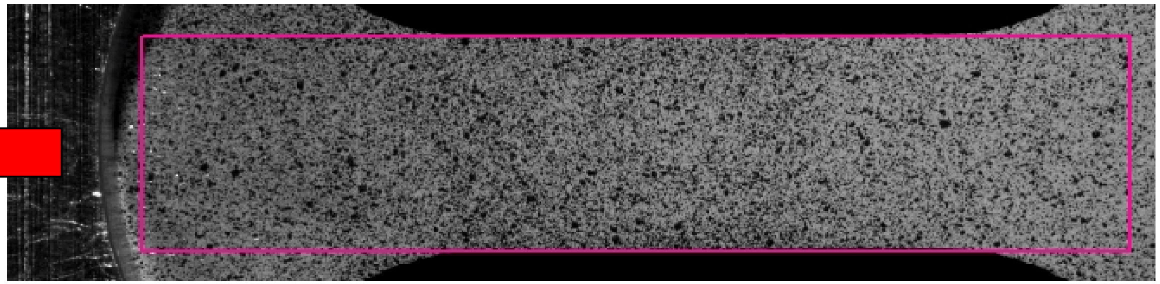
Dynamic Tensile Testing using an « Arbalete system » equipped with digital high speed camera for dynamic strain measurement (Strain-rates : $10^2 \sim 5.10^3\ s^{-1}$).

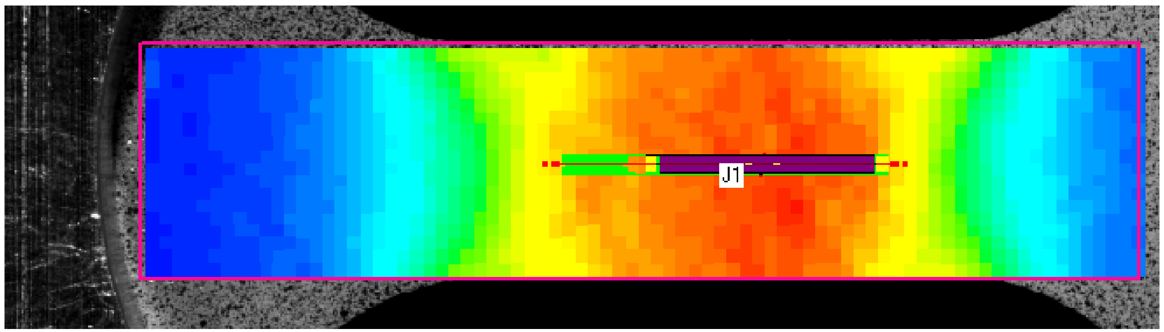


2. – An Example of Research and Development in Impact Engineering

Materials behavior under High strain-rate loadings and shock-wave Loadings (Dynamic Plasticity).

"Mouchetis Paints " deposited on the effective part of the tensile specimen (Aluminum Alloy : AA5083)





2. – An Example of Research and Development in Impact Engineering

Materials behavior under High strain-rate loadings and shock-wave Loadings (Dynamic Plasticity).

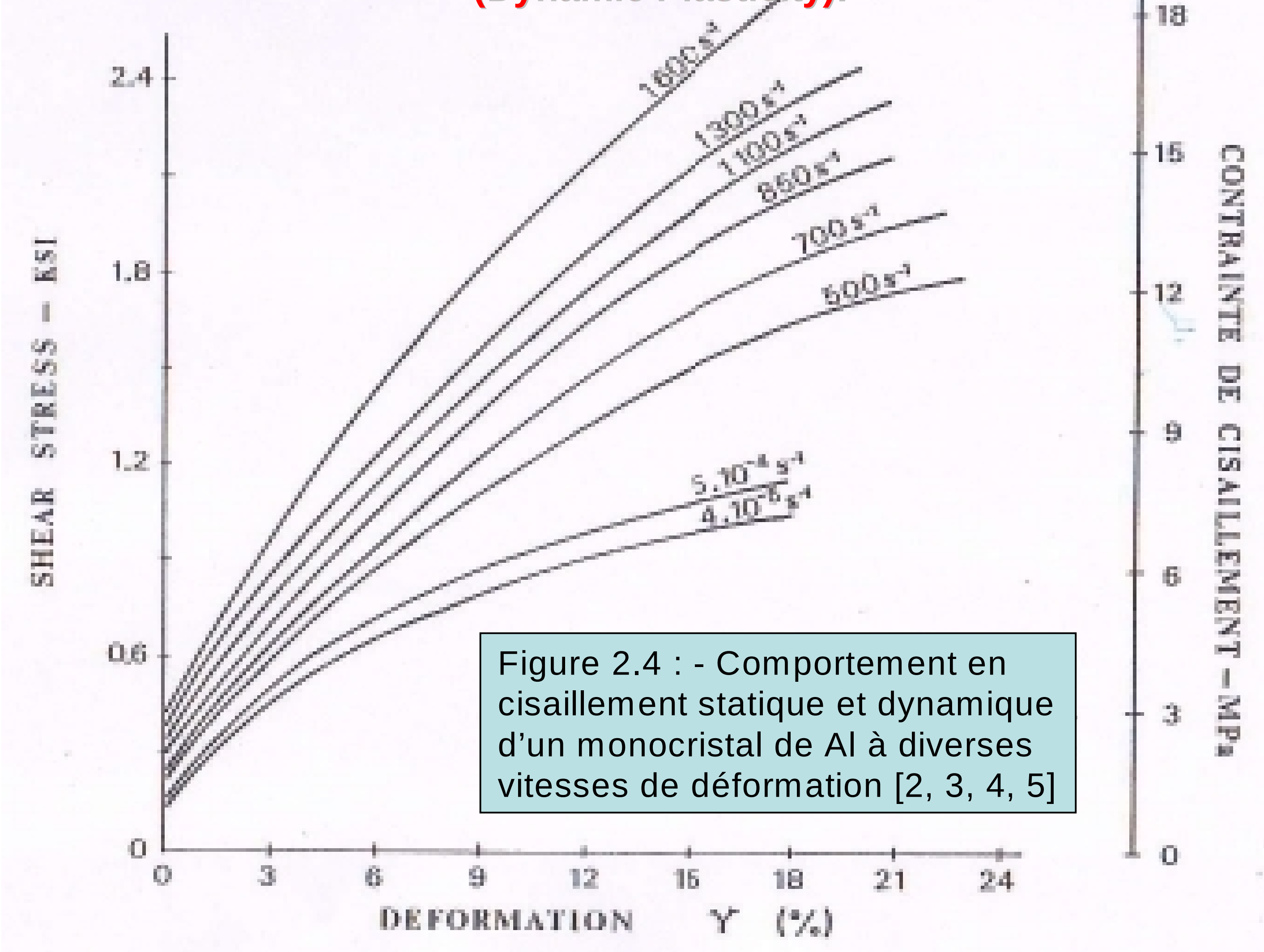


Figure 2.4 : - Comportement en cisaillement statique et dynamique d'un monocristal de Al à diverses vitesses de déformation [2, 3, 4, 5]

Static and Dynamic Shear Stress-Strain Curves of Alumnium Single Crystals deformed under various strain-rates ($4x10^{-5}$ to $1.6x10^{3}$ s^{-1})

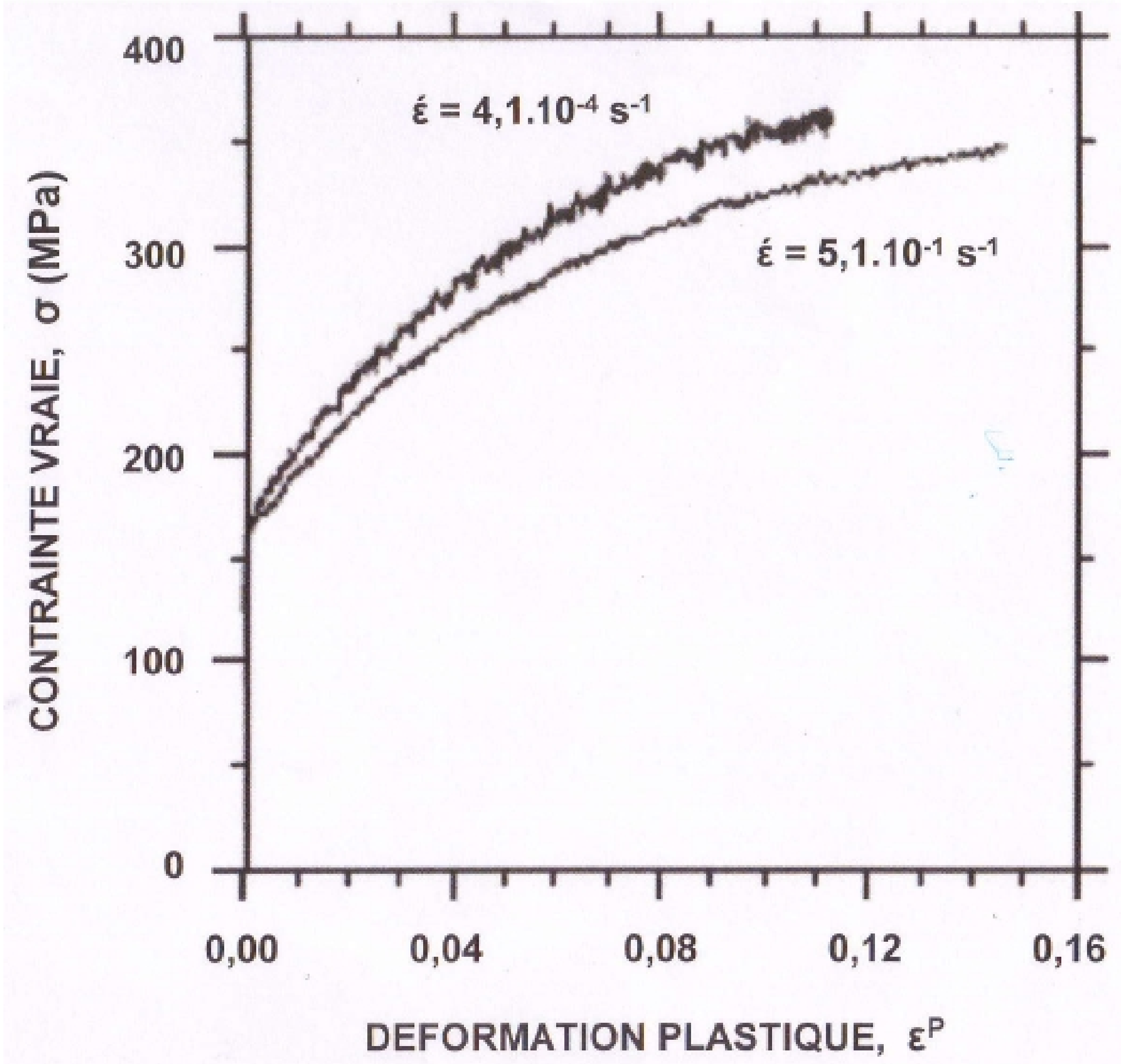


Figure 2.18. : - Influence du Phénomène de Portevin-Le Chatelier (PLC) sur un alliage Al-Mg [21]. Courbes « ciselées » dans le domaine de la plasticité.

(a) **Reverse Strain-Rate Sensitivity**
Portevin-Le Chatelier Effects
Dynamic Strain-Ageing

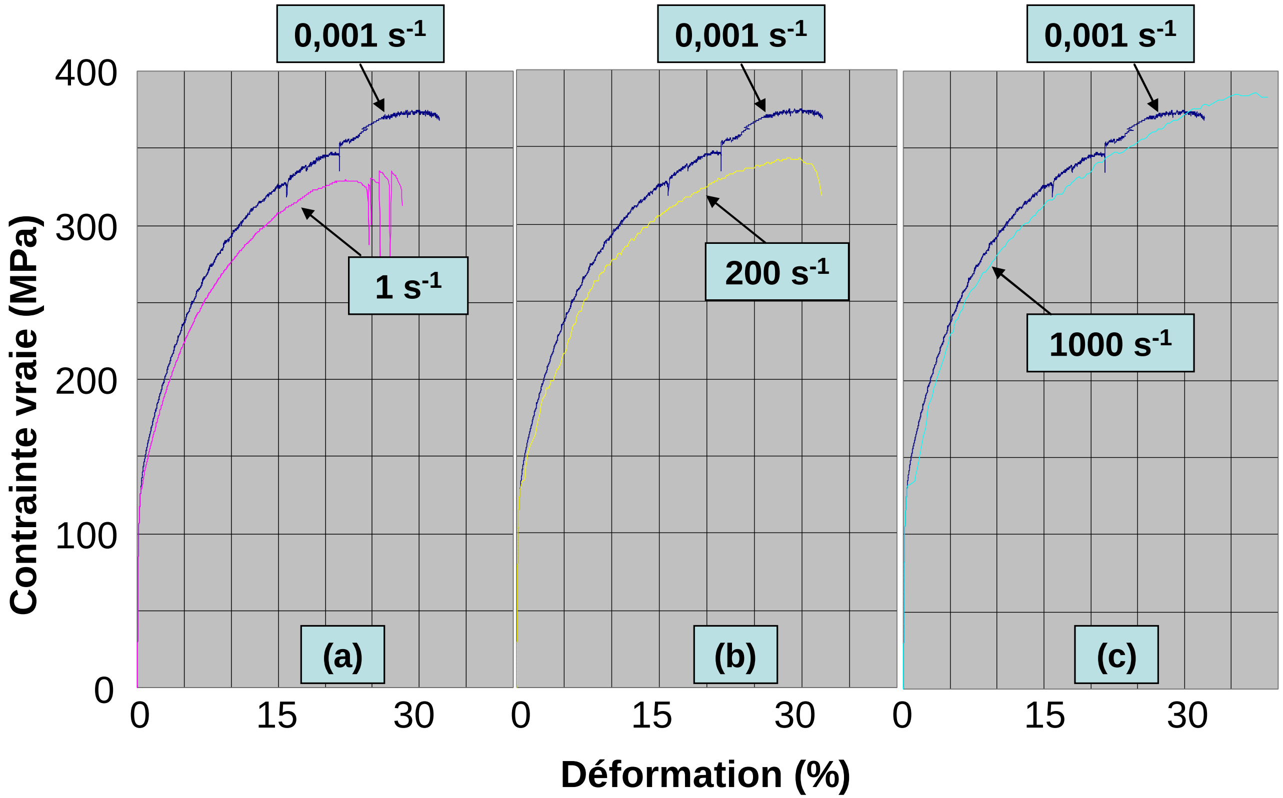
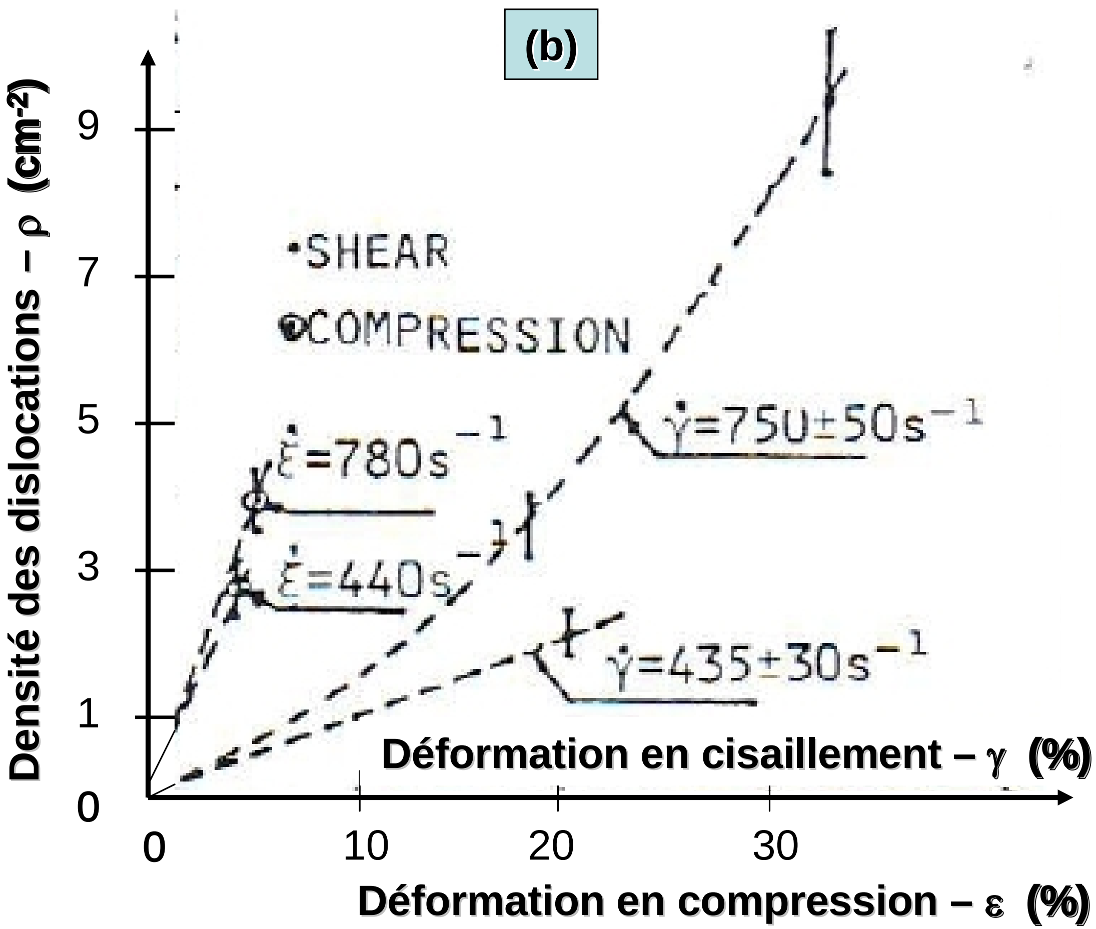


Figure 3.7 : - Sensibilité inverse à la vitesse de déformation de l'alliage d'aluminium 5083-H111



<u>Figure 2.14(b)</u> : - Relation entre la densité des dislocations et la déformation, compression et cisaillement d'un monocristal de Fe-3% Si à diverses vitesses de déformation [11, 13].

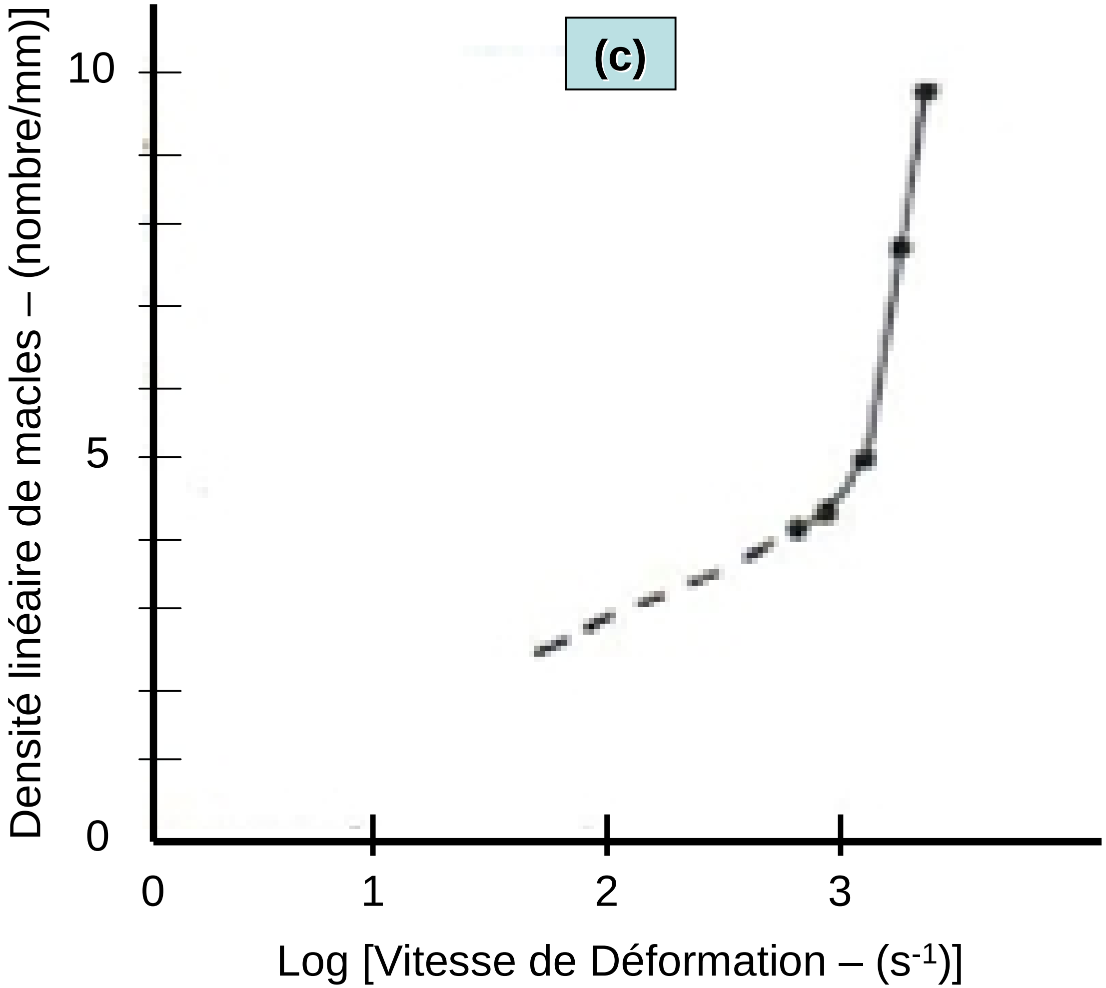


Figure 2.14(c) : - Relation entre la densité linéaire des macles et la vitesse de déformation d'un monocristal de Fe-3% Si à diverses vitesses de déformation [11, 13].

Materials behavior under High strain-rate loadings and shock-wave Loadings (Dynamic Plasticity).

➔ Chiem et al. has proposed the following equation to calculate this « Twinning Critical Stress » :

$$\tau_w = (1/n).\{(\gamma_{fe}/b_s) + (G.b_s/2r)\}$$

where

- τ_w, Threshold of Twinning critical stress,
- **n,** Stress concentration coefficient at the twin-tip,
- γ_{fe} , Stacking fault energy of materials,
- b_s Burgers vector of screw-dislocations,
- **G ,** Shear modulus of the material,
- **r,** Radius of the dislocation-archs entering in interaction with the twins.

➔ This formula is based on the Concept of co-existence of the systems of dislocations-slips and systems of twinning considering that dislocations motion and twins propagations are permanently under interactions as soon as the conditions are in favor of twinning.

3. – Some Contributions and Partnerships (1)

Some pertinent Problems

3.1. – Missile defeat : - Defending against intercontinental ballistic missiles ICBM (1)

NATO countries need to know if our nuclear weapons, detonated in the upper atmosphere in the vicinity of an incoming ICBM, would damage enough the missile to prevent it from accomplishing its destructive purpose.

3.1.1. – How nuclear explosions damage Space Targets ?

Reentry vehicles can be damaged and killed by high-energy x-rays emitted from the exploding nuclear device :

- Travelling relatively unattenuated
- x-rays impinge on and absorbed by the target, rapidly heating the skin.
- Rapid deposition of energy generates Shock-waves ➔ short-lived tensions

Dynamic Fracture Solutions

3.1. – Nucleation and Growth (NAG) Approach to to Fracture (1)

A way was needed to relate the size of a nuclear weapon, the distance from the target and the damage to the target.

3.1.1. – How nuclear explosions damage Space Targets ?

Challenge : - Develop a method to predict the extent of fracture damage knowing:

- the size of the nuclear weapon;
- Its proximity to the target;
- The nature of the material of the target.
- Tensions cause various levels of fracture damage.
- Not practical to perform actual upper-atmosphere experiments.

3. – Some Contributions and Partnerships (2)

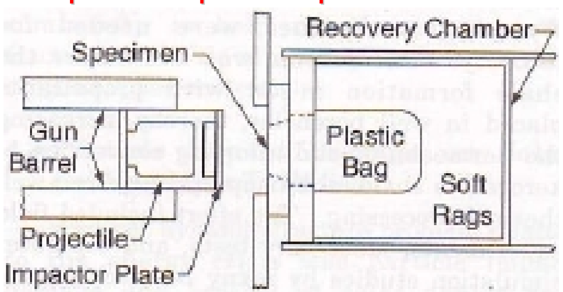
Some pertinent Problems

3.1.2. – How to perform experiments using nuclear weapons and ICBMs and not on upper-atmosphere ?

(a) - Algorithm sought by performing underground nuclear tests;

(b) – Laboratory simulation tests using non-nuclear loading sources;

Use Gas to perform gun plat//plate impact experiments.



(c) – Computations based on theory. Development of the NAG concept by a team in SRI (USA).

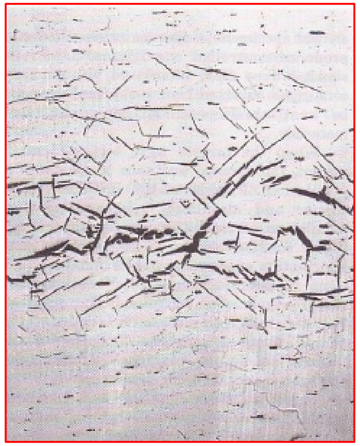
➔ How to describe these observations of microstructures ?

Dynamic Fracture Solutions

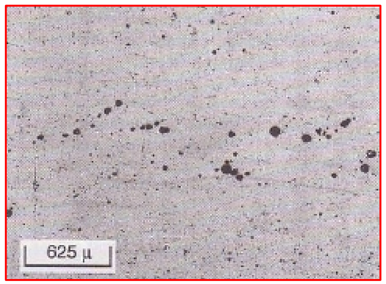
3.1.2. – How to perform experiments using nuclear weapons and ICBMs and not on upper-atmosphere ?

Test-specimens : - Microstructures

Brittle and ductile micro-failures on polished cross-sections of plate impact specimens.



- Brittle fracture of Armco Iron :
- microcracks.



- Ductile fracture of 1100 Aluminum :
- Population of voids.

3. – Some Contributions and Partnerships (3)

Some pertinent Problems

3.1.3. – How to describe these observations of microstructures ?

➔ **Required development of :**

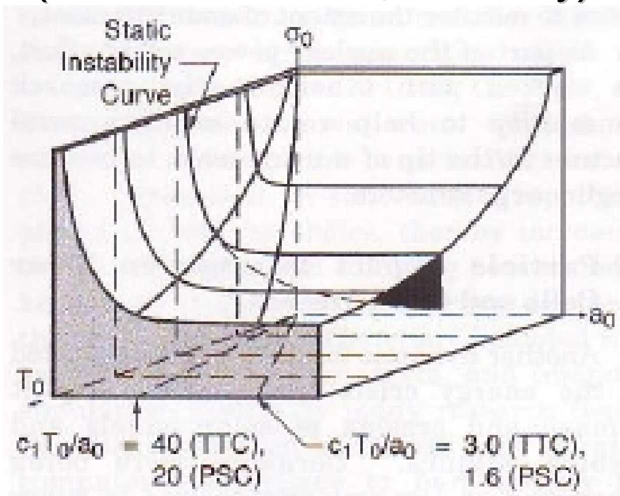
(1) – New criteria for :
- * brittle fracture
- * ductile fracture
- * instabilities

(2) – Short Pulse Fracture Mechanics
- * Propagation of cracks
- * Temperature at the tip of a rapidly propagating crack
- * Brittle-Ductile fracture Transition phenomena
- * Instabilities and shear banding.
- * Hypervelocity impact

Dynamic Fracture Solutions

➔ **Identification of Instability in short pulse fracture mechanics**

Modification of classical Griffith-Irwin instability criterion to include time (Prof. J.F. Kalthoff, Germany)



Instability diagram for cracks in polycarbonate loaded by a short stress pulse.

TTC = through-thickness cracks

PSC = penny-shaped cracks

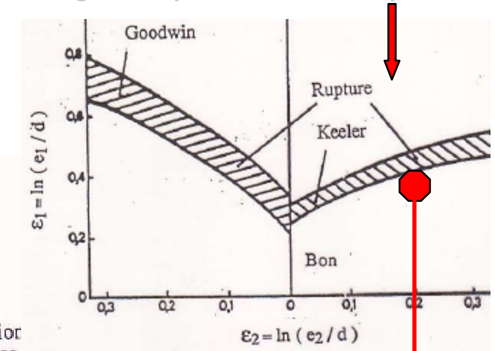
3. – Some Contributions and Partnerships (4)

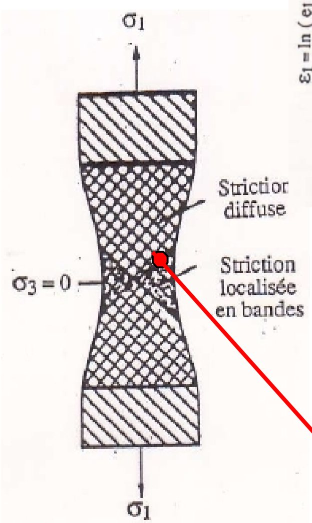
Some pertinent Problems

3.1.3. – How to describe these observations of microstructures ?

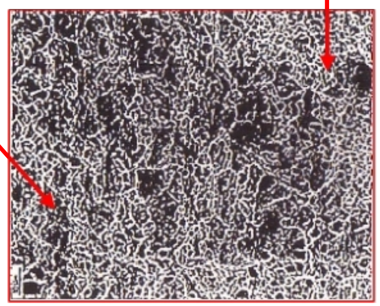
➔ **Development of Ductile fracture criteria**

(a) Forming limit diagram (Plane Stress)





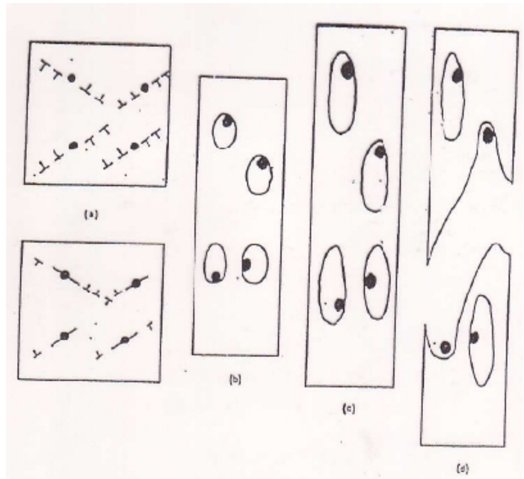
Steel 0.30 C-1 Cr-0.25 Mo.



(b) Tensile Test

Dynamic Fracture Solutions

(c) Voids growth mechanism



a. - Nucleation of voids

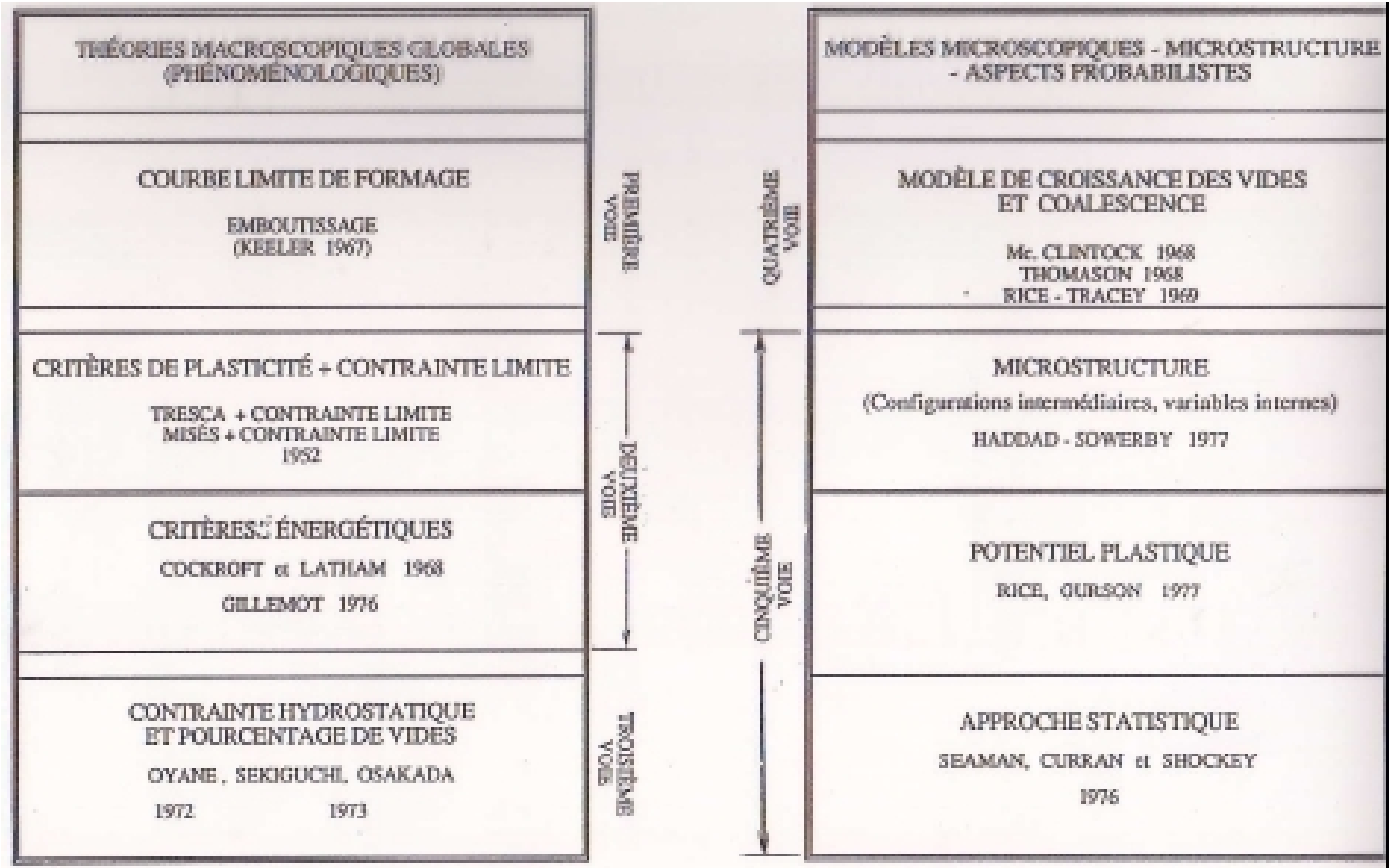
b. and c. - Growth of voids

d. - Coalescence of voids

- Evolution of developed criteria is shown in the table below.
- All these developed tools can be used to solve many new challenging applications.

3. – Some Contributions and Partnerships (5)

Evolution of Ductile Fracture Models



3. – Some Contributions and Partnerships (6)

3.2. – Particle Impact Damage on Solar Cells and Gas Turbines

*** Due to energy crisis, ceramics were being considered as low-cost alternatives to superalloys for stators, rotors and other high temperatures engine components because of their :**

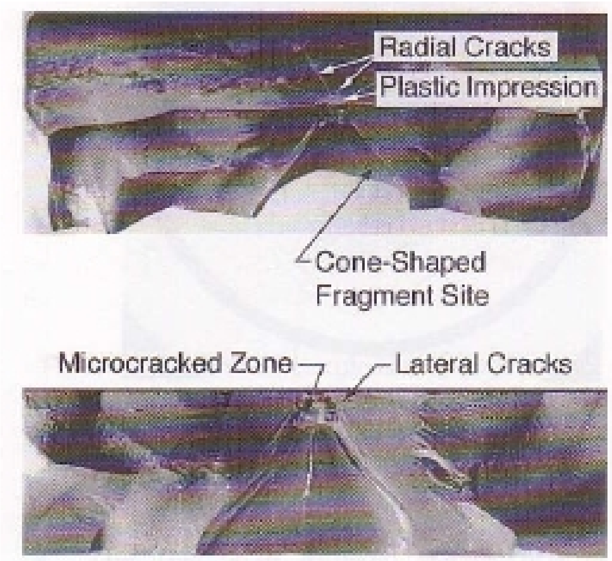


Figure : - Particle impact damage in Si_3N_4.

- High strength at elevated temperatures,
- low density
- low coefficient of thermal expansion
- high oxydation resistance.

Problem :

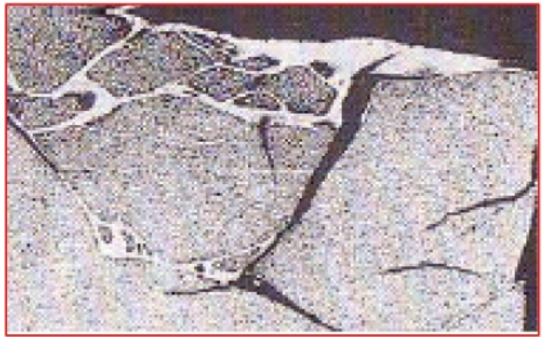
➔ Large dependance on flaw size and distribution

Tests are performed using light gas gun launching small Steel or WC spheres at 300 m/s and to study the effects of surface oxydation, temperature and transformation toughning.

3. – Some Contributions and Partnerships (7)

3.3. – Armor, Debris and Shear bands

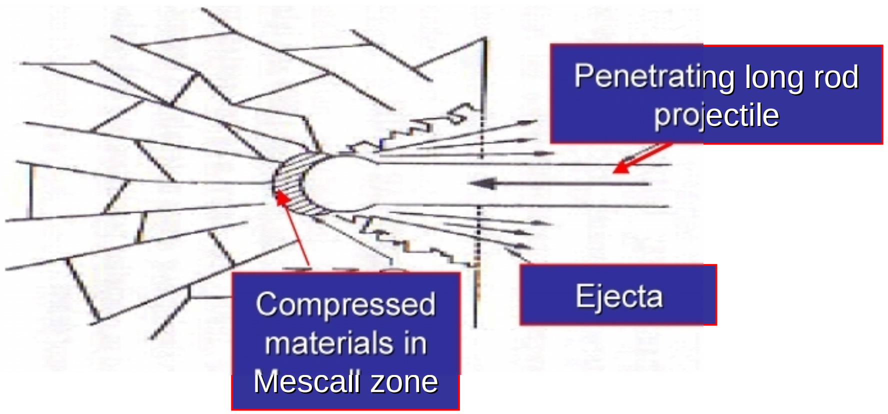
New armor materials and designs through 1970s to early 1990 required R&D performance in predicting penetration and debris generated at the back of armor.



Shear bands in steel armor developed near hole generated by a penetrator

- After perforation of armor by a projectile, shear bands (white etching) were observed on surface of etched armor plate as shown on left side figure.
- Shear bands was described in by Zener and Hollomon (1944) as thermal-mechanical instabilities occurred when thermal softening overcomes work-hardening.

* Picture of fragment spray from armor when impacted by a long rod projectile obtained by Triple flash X-Ray



Model of penetration of ceramic armor by a long rod projectile.

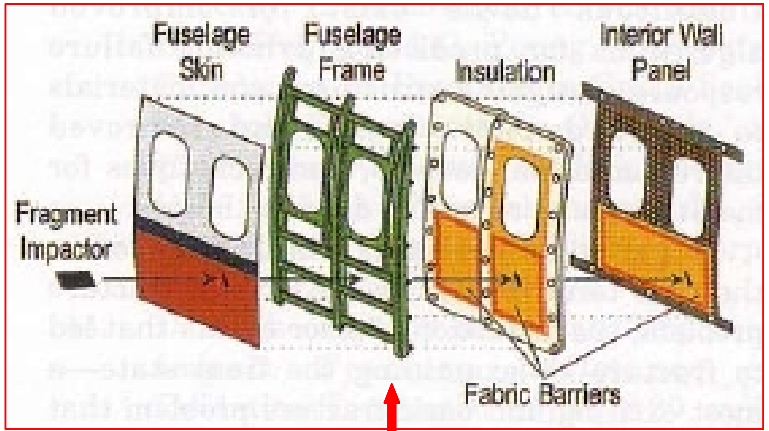
4. – Some Contributions to human protections (1)

4.1. – Protection from Engine fragments impacting on Commercial Aircraft

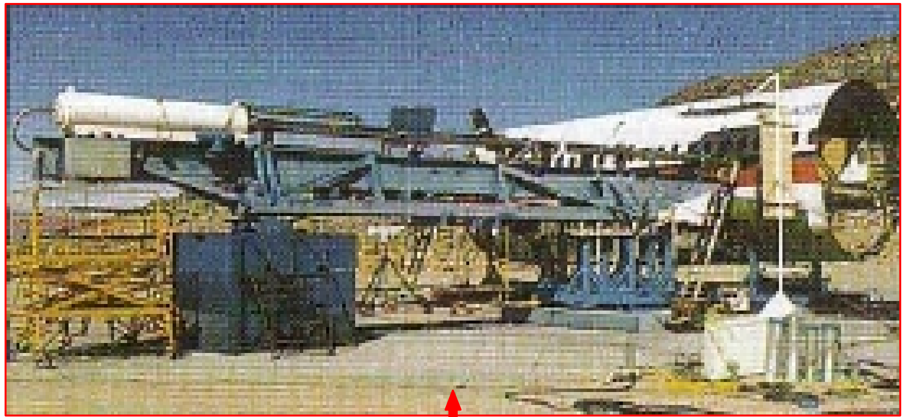
Lightweight Fabric Barriers were developed to protect the passengers and the aircraft against engine fragments.

➔**In Rare occasions** : Rotor disk of a propulsion engine on commercial aircraft fails and perforates the containment structure in the nacelle, showering a section of the fuselage with engine debris.

➔ **Aerospace agencies** initiated programs of designing and evaluating barriers using high strength polymer fabrics that shall be installed in the fuselage walls for protection against engine fragments.



Location of ballistic fabrics through an Exploded View of the fuselage wall in a commercial jet-liner

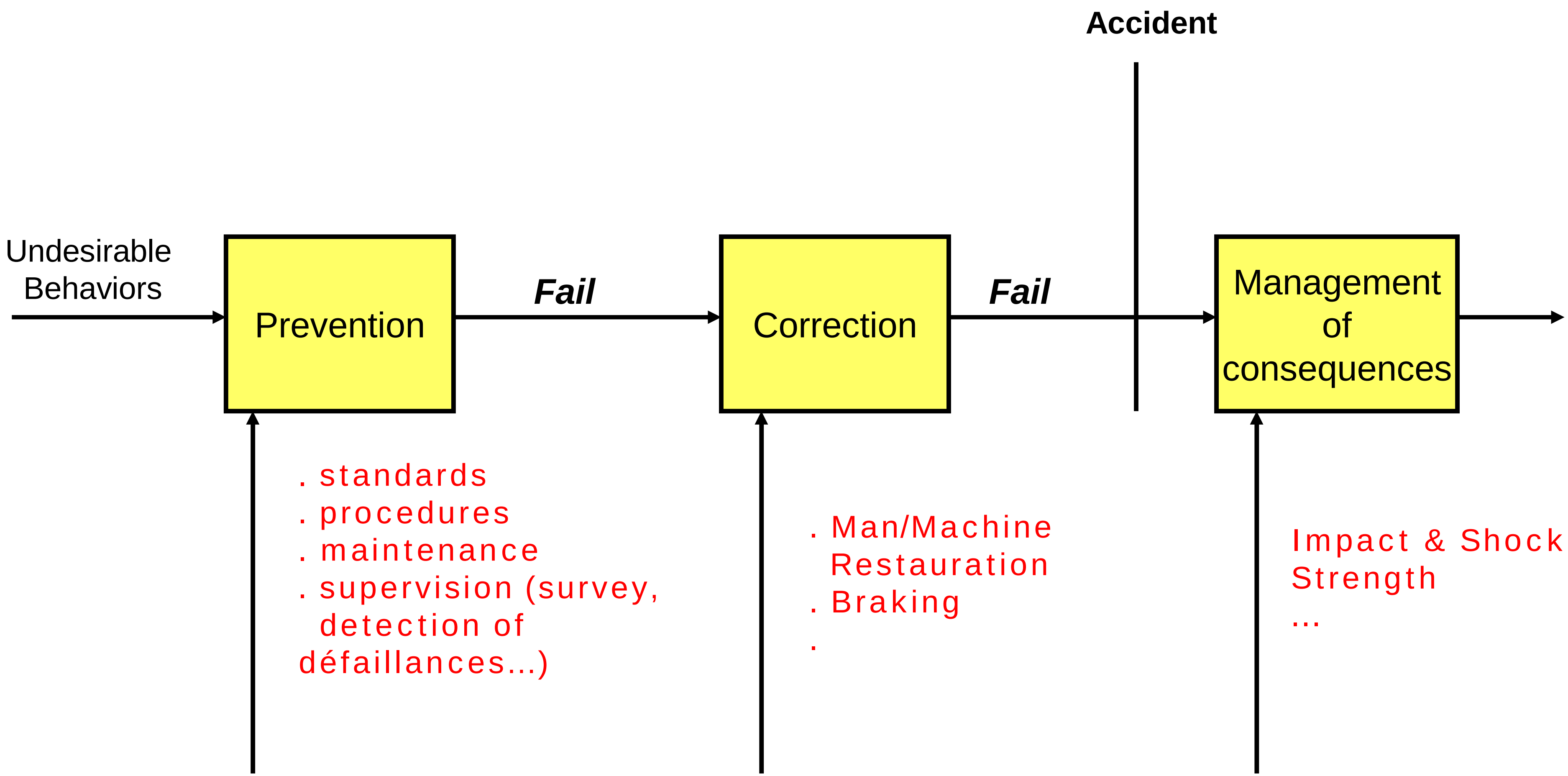


A System for full-scale testing of engine fragment barriers.

4. – Some Contributions to human protections (2)

4.2. – Transport Security and Human Safety (1)

OBJECTIVES and Strategies : - The 3 Transport Security Stages



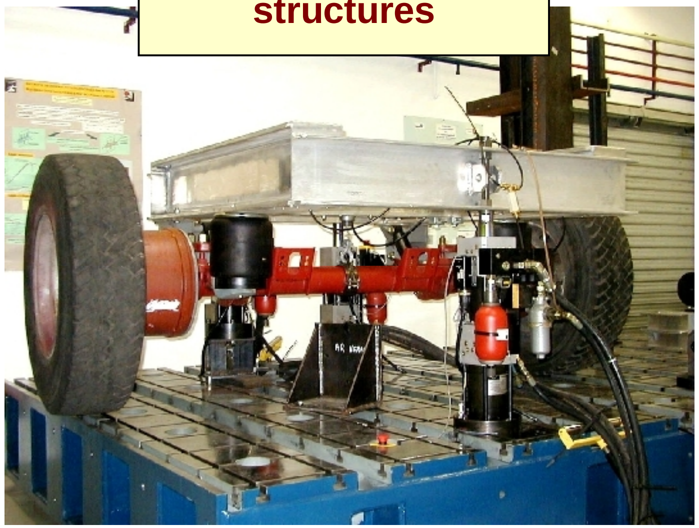
4.2. – Transport Security and Human Safety (2)

1 - PREVENTION and TREATMENT OF ACCIDENTS AND DEFECTIONS :
MECHANICAL APPROACH

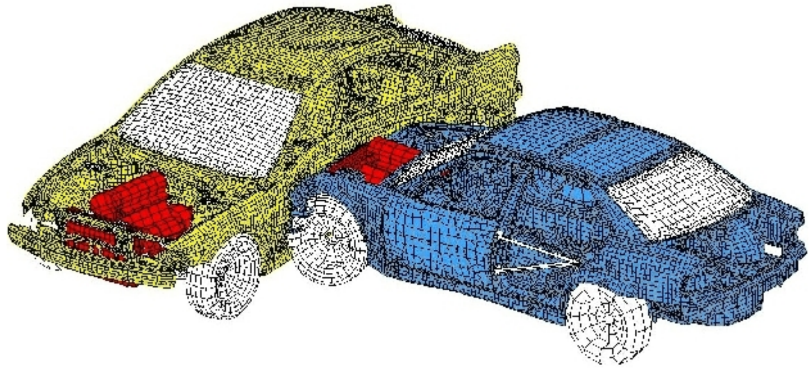
Analysis and Design of Materials and Strengthened Structures
according to 2 objectives

Preventive Security	Security Design
to reduce the risks of accident	to limit the effects of these accidents
FATIGUE	CRASH

Fatigue and Fracture of materials and structures



Non-Linear Dynamic Damage and Fracture



→ Damage Modelling,

→ Follow-up of the progress of the event

4.2. – Transport Security and Human Safety (3)

2 - BIOMECHANICAL APPROACHES OF THE SECURITY : MOTION AND PRE-CRASH

Scientific or Technical Surveys

Laws of command of human motions

Identification of Motion Controls

Predictive Models to generate the behavior of human being.

4.2. – Transport Security and Human Safety (4)

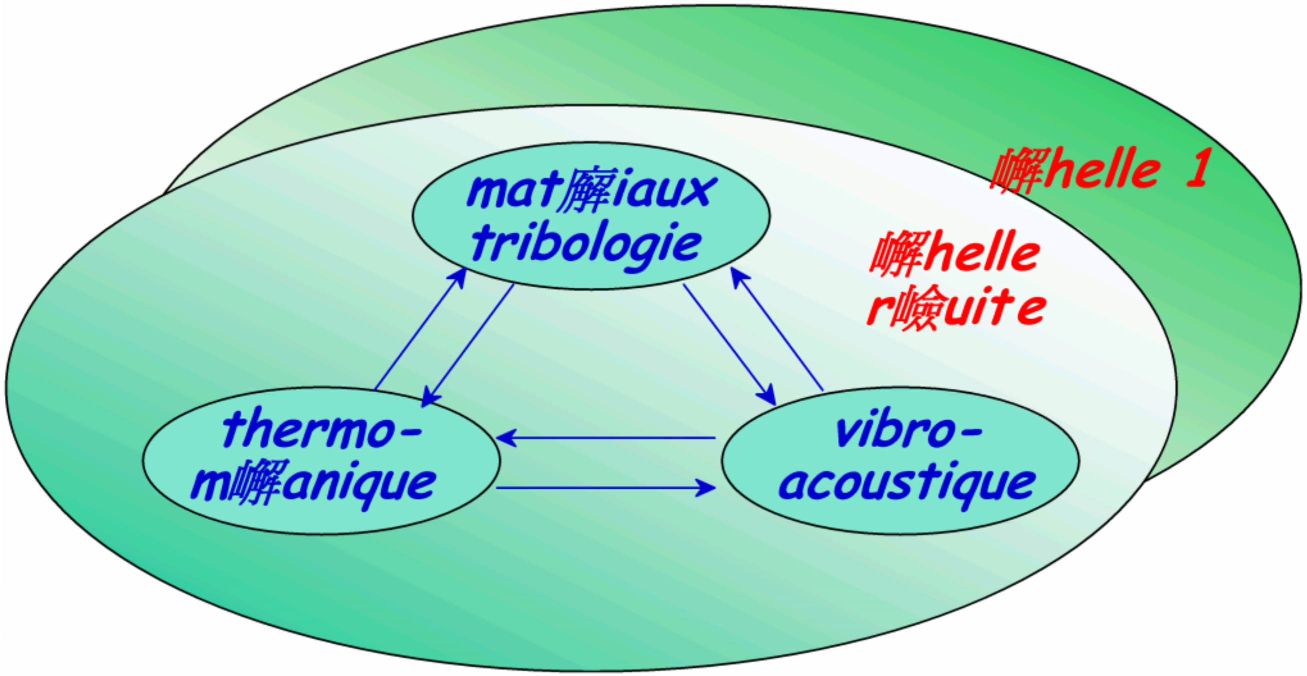
4 – HUMAN FACTORS : DEFECTIONS AND PARADES

- **Identify the causes of human defections.**
- **Define the parades and barriers solutions to prevent and correct the human errors and limit the risky consequences.**

MULTI-DISCIPLINARY EXPERIMENTAL METHODS

4.2. – Transport Security and Human Safety (5)

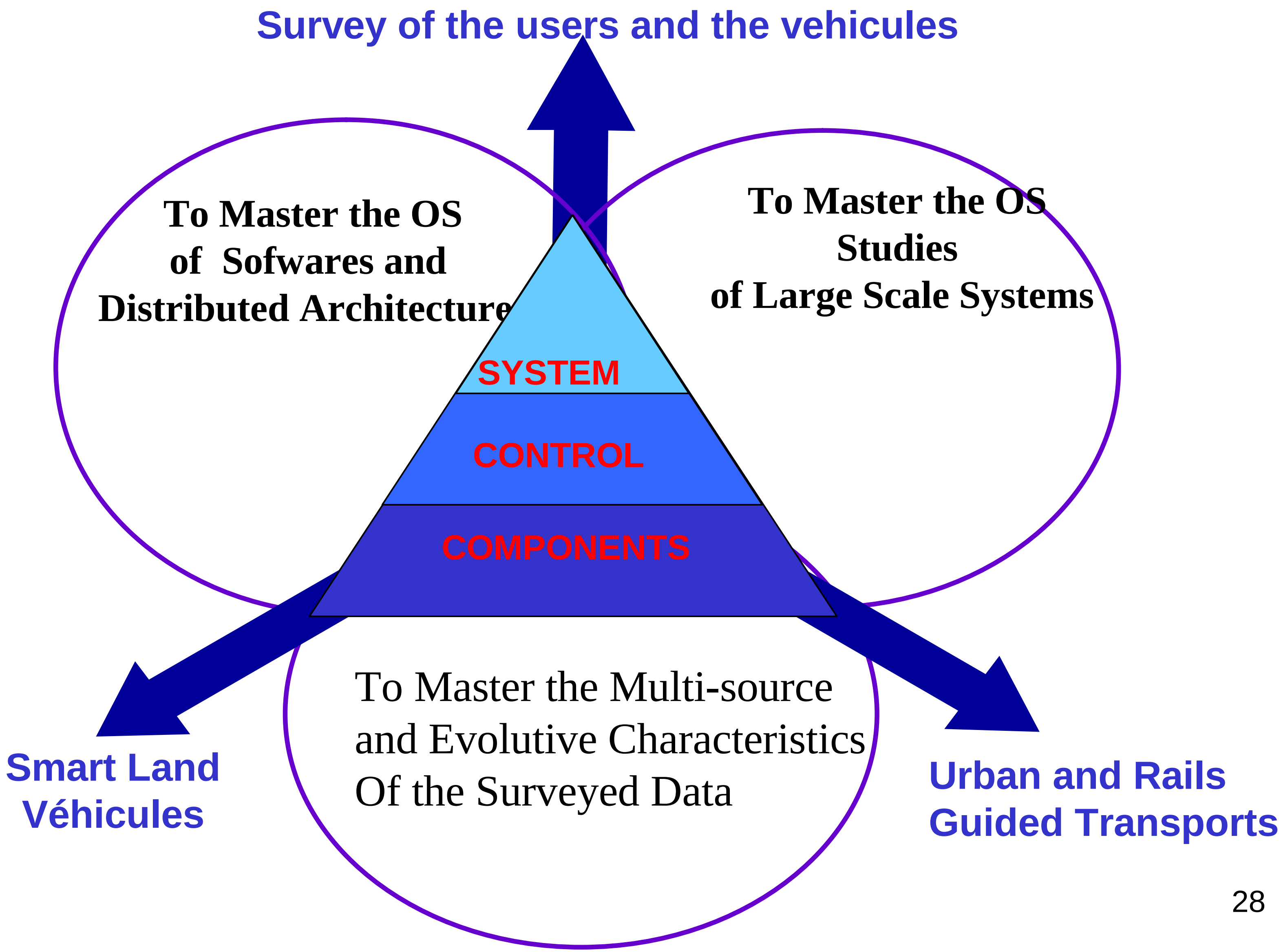
5 - MULTI-PHYSICAL ET MULTI-SCALE APPROACHES OF BRAKING.



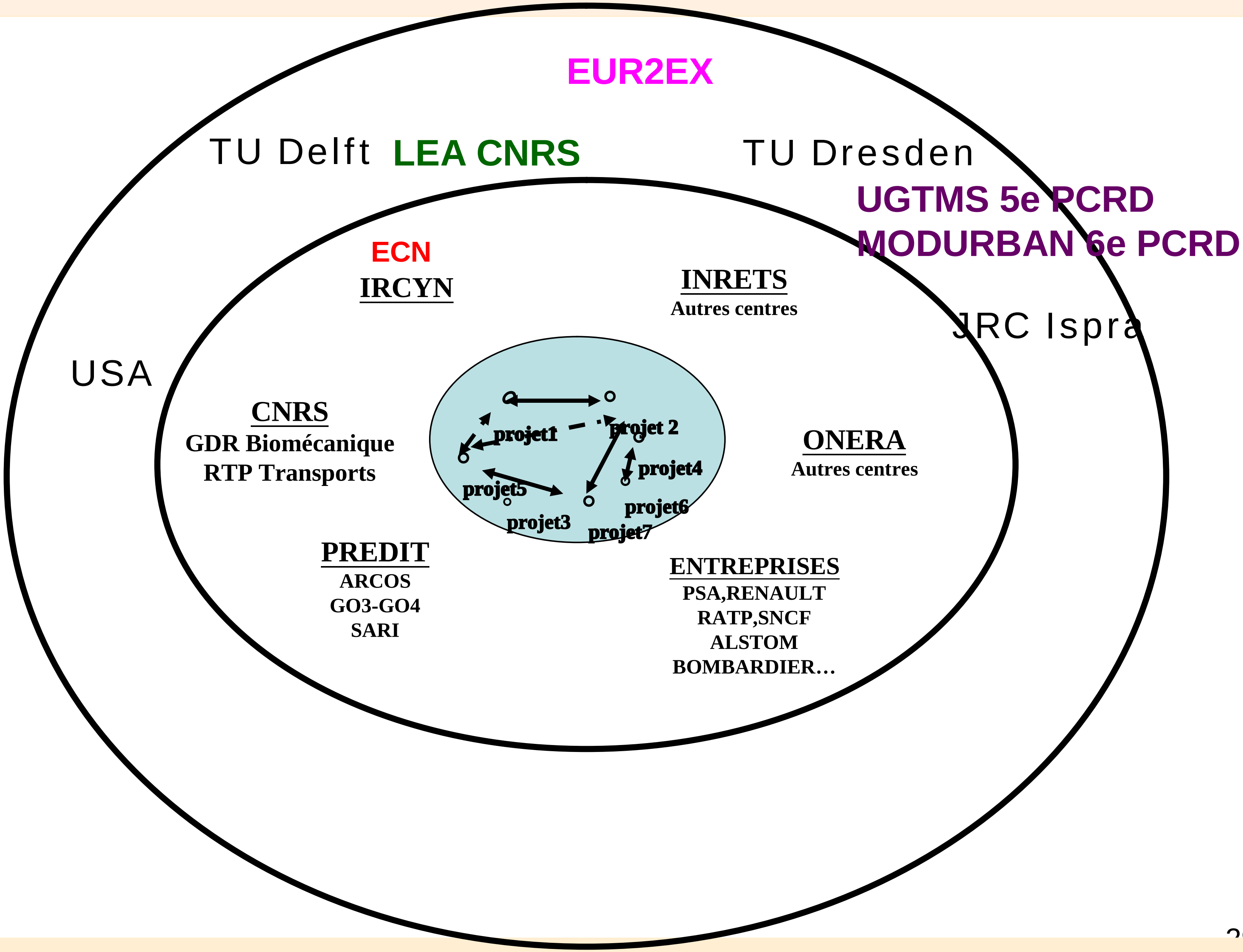
Requirement to take into account the inter-disciplinary couplings and the bridging of surface contacts to the system.

4.2. – Transport Security and Human Safety (6)

6 - SURETE DE FONCTIONNEMENT : APPROCHES SYSTEME



3 – International Positioning



¤ Contexte : Endommagement biomécanique de la tête sous chargement dynamique.

Endommagement & Rupture

1. **– Eléments protégeant le cerveau :**
   *** Peau et os crâniens**

2. **- Eléments intracrâniens :**
   *** Veines; * Artères; * Cerveau;**
   *** Liquide cérébro-spinal (LCS)**

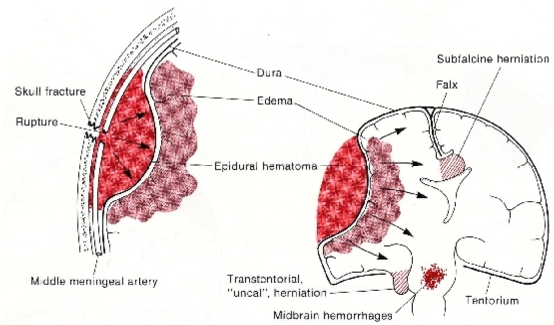
Liaisons ???

Répartition spatiale des éléments dans un crâne normal

Veines | Artères | Cerveau | LCS

Répartition spatiale des éléments dans un crâne endommagé

Veines | Artères | Cerveau | LCS

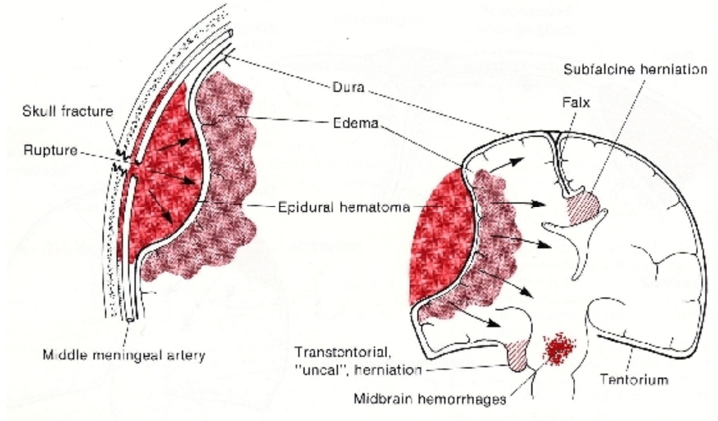


Exemple : - Hématome épidural
* Accumulation du sang entre l'os crânien et la duremère.

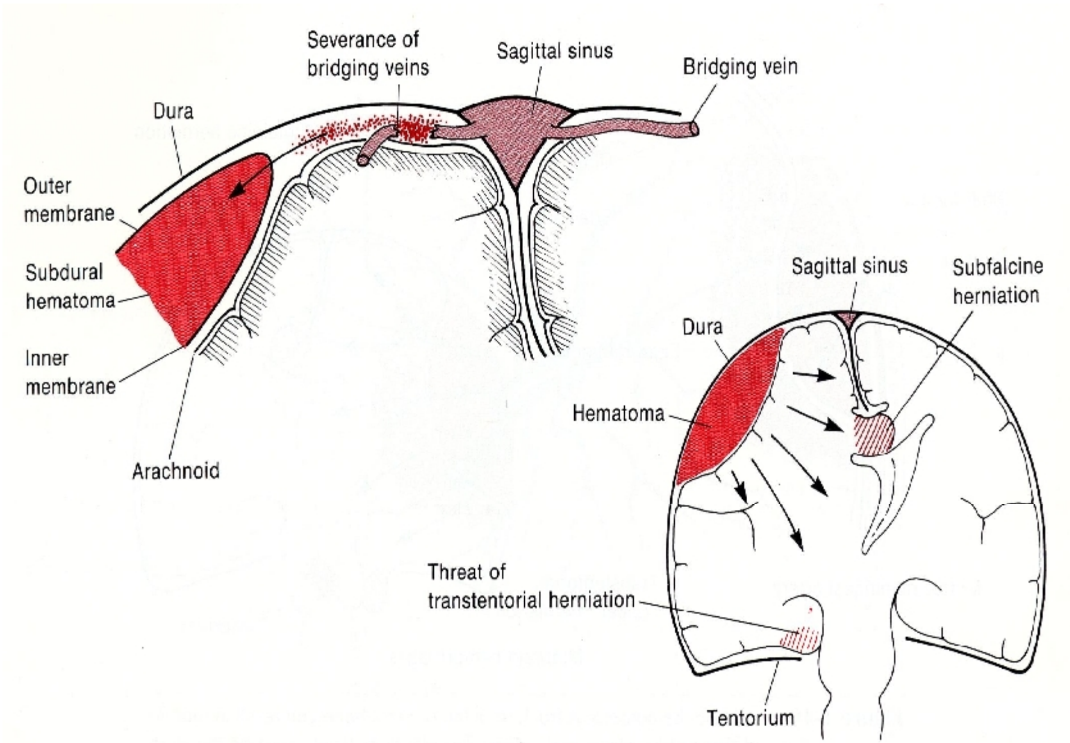
Trois types d'hémorragie interne :

1. – Hématome épidural
2. – Hématome sous-dural
3. - Hémorragie intracérébrale

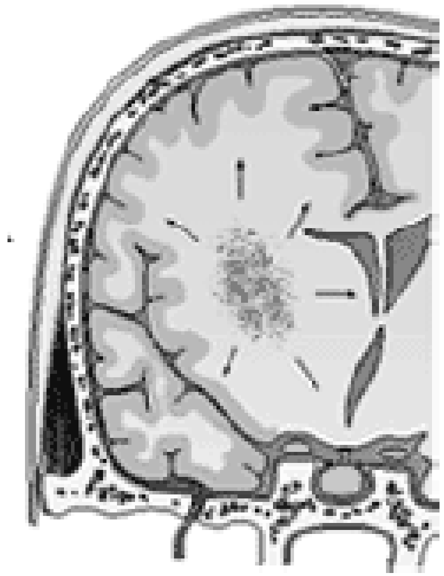
1. – Hématome épidural



3. – Hématome sous-dural intra



3. – Hémorragie intracrânienne

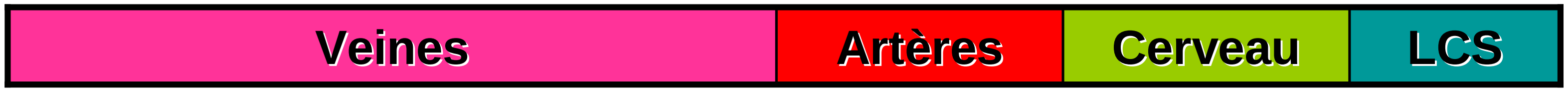


4.2. – Transport Security and Human Safety (6)

Répartition spatiale des éléments dans un crâne normal

Répartition spatiale des éléments (Cas de l'hématome épidural)

Répartition spatiale des éléments (Cas de l'hématome sous-dural)



Répartition spatiale des éléments (Cas de l'hémorragie intracrânienne)

What happens to neurons after a stroke?

- Closest ones die quickly
- Cells in *penumbra* might die over days or weeks, but can sometimes be protected
- How do they die? *Over*stimulation!

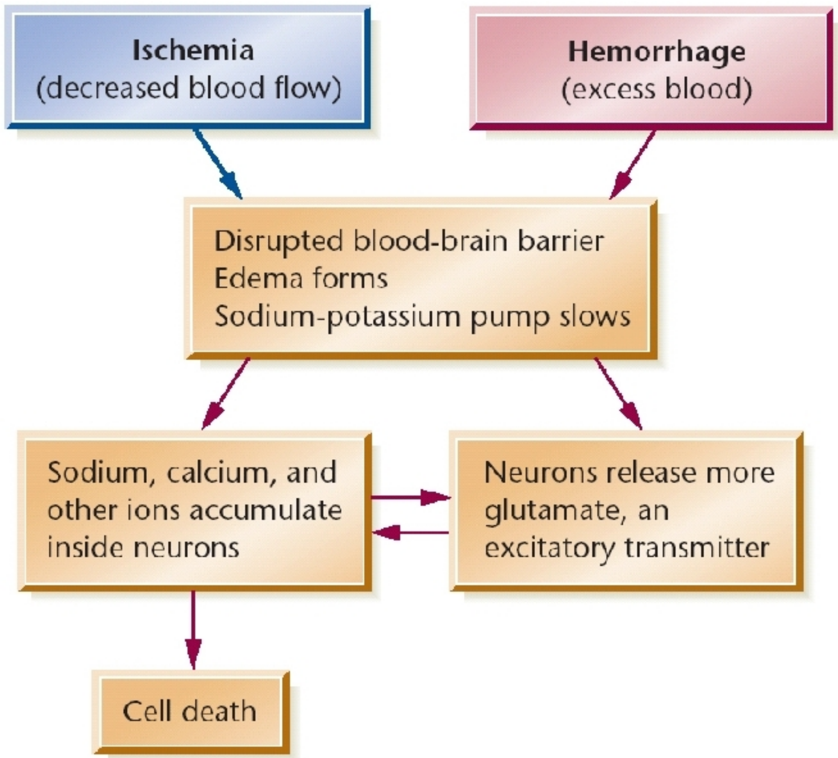


Figure 5.20, p127

4.2. – Transport Security and Human Safety (6)

¤ Les Outils biologiques :

1. – Modélisation physico-chimique :

   * Moyens d'évaluation des endommagements biologiques

   Identification :

   - Etats d'endommagement biologique du cerveau
   - Etats d'endommagement mécanique du crâne
   - Causes et Effets

2. - Simulation des milieux vivants

3. - Modèles sur animaux : - Essais sur veaux vivants;
   - Essais sur veaux anesthésiés;
   - Essais sur veaux morts.

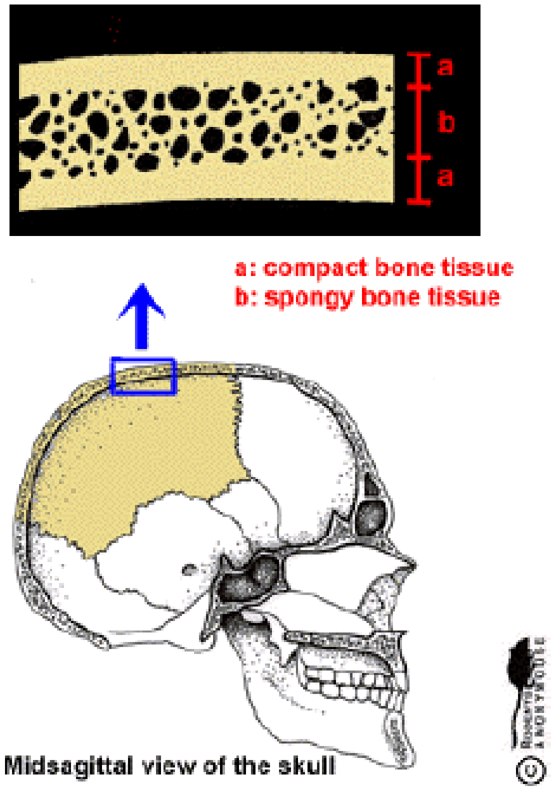
4. - Etudes chez l'homme : - essais sur cadavres;
   - suivi clinique, radiologique, etc. ...

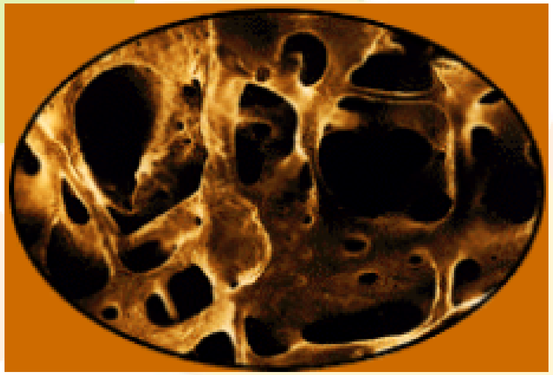
5. - Simulation et extrapolation sur crâne numérique, ...

4.2. – Transport Security and Human Safety (6)

- **Hétérogénéités/Crash des matériaux biologiques osseux**

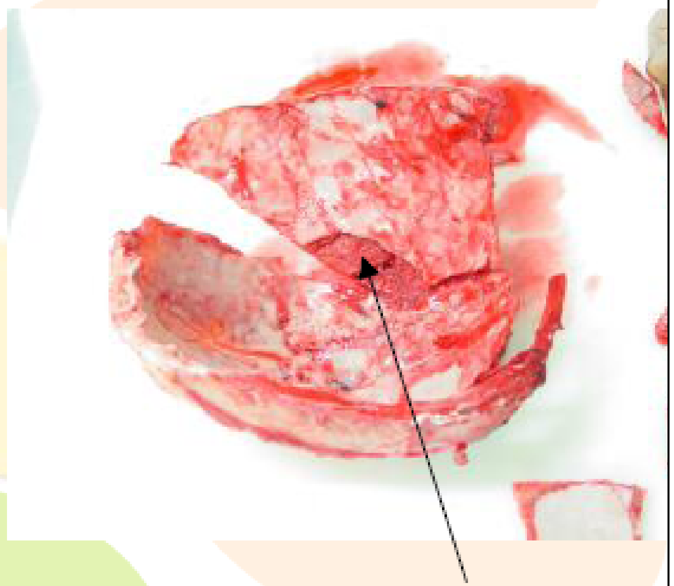
  Crâne humain : os plats composés d'un os spongieux (diploë) pris en sandwich entre deux os compacts (tables externe et interne)





Structure diploë

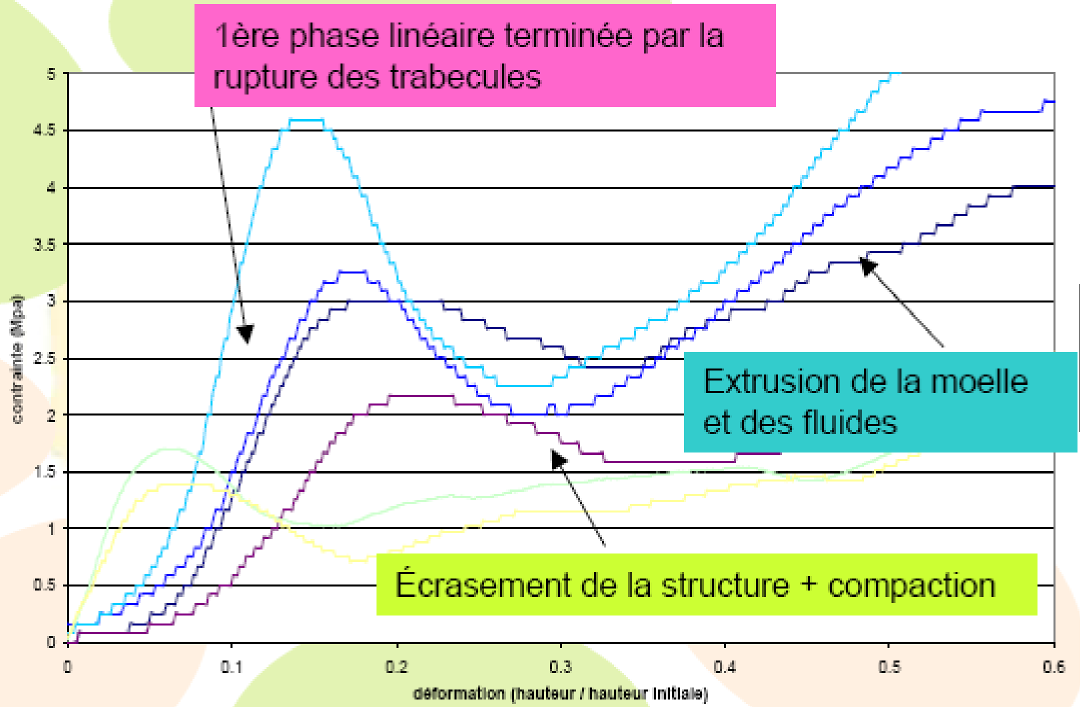
Structure table



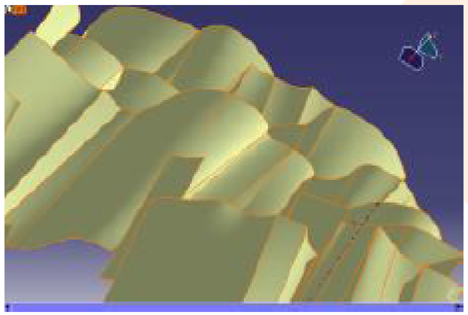
Cisaillement de la table interne

4.2. – Transport Security and Human Safety (6)

- **Essais de compression sur os spongieux frais de bovins**

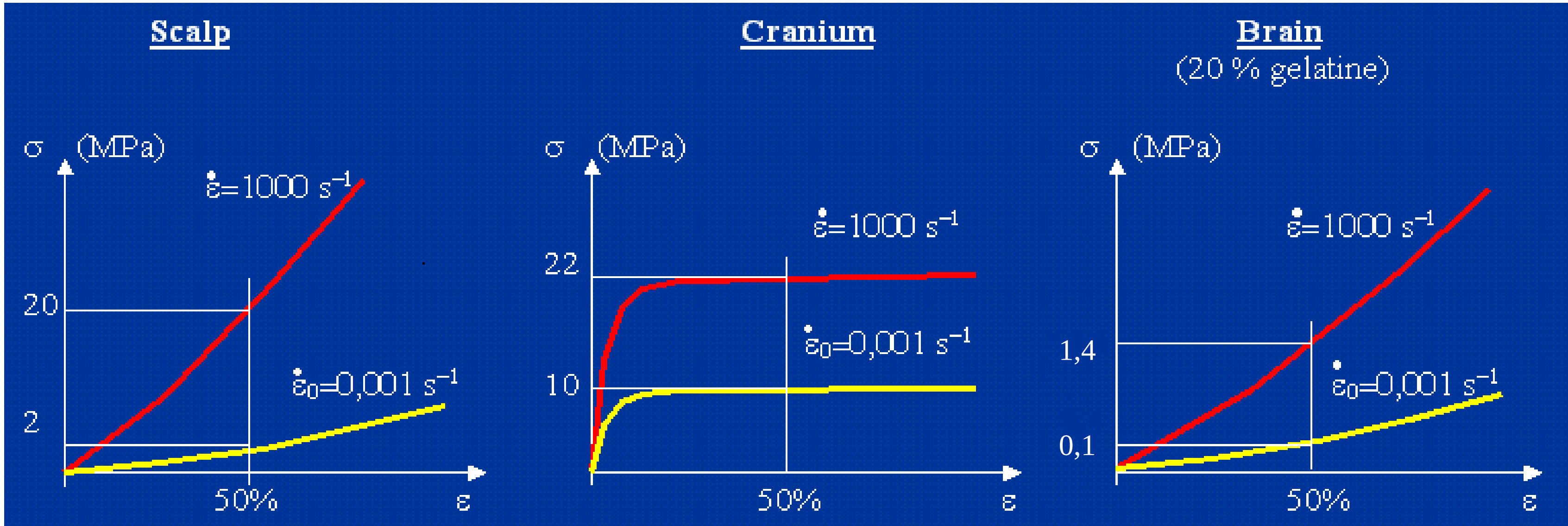


Reconstitution géométrique pour modélisation EF



Forte dispersion des résultats due à une forte hétérogénéité matérielle, inter-individus et en fonction de la zone de prélèvement pour un même individu

Materials Behaviour



Water

Compressibility factors :

C_1, C_2, C_3, C_4, C_5

C = 1435 m/

$\mu = 10^{-6}\ m^2s^{-1}$

Projectile

Rigid sphere

ϕ = 45 mm

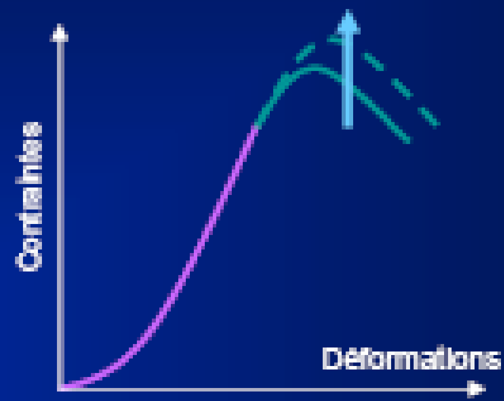
Weight = 20 g

Initial velocity V_0 = 16, 25, 35, 80 and 110 m/s

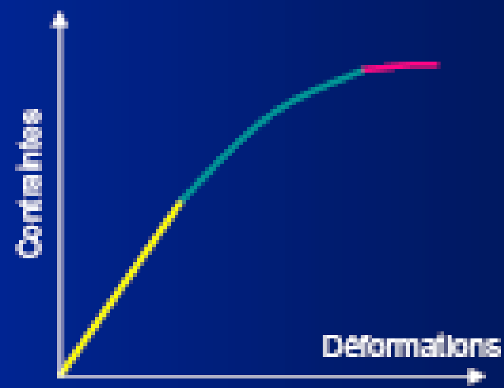
4.2. – Transport Security and Human Safety (6)

Comportement des tissus biologiques

Mous (ligaments, viscères…)
- hyperélastique (non linéaire)
- endommageable
- visqueux

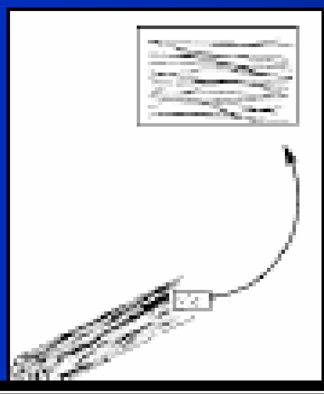


Durs (os)
- Elastique (linéaire)
- endommageable/fragile
- plastique



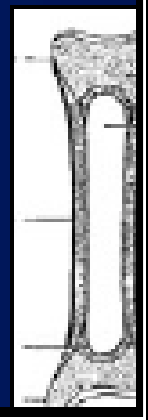
Le ligament

- Fibreux (fibres réticulées et élastiques),
- Fibres orientées,
- Collagène (organique),



L'os

- constituant de base : lamelle (collagène)
- 2 types d'os : compact et spongieux (porosité)
- 2 parties : organique (collagène) / minérale (hydroxyapatite)



What happens to neurons after a stroke?

- Closest ones die quickly
- Cells in *penumbra* might die over days or weeks, but can sometimes be protected
- How do they die? *Over*stimulation!

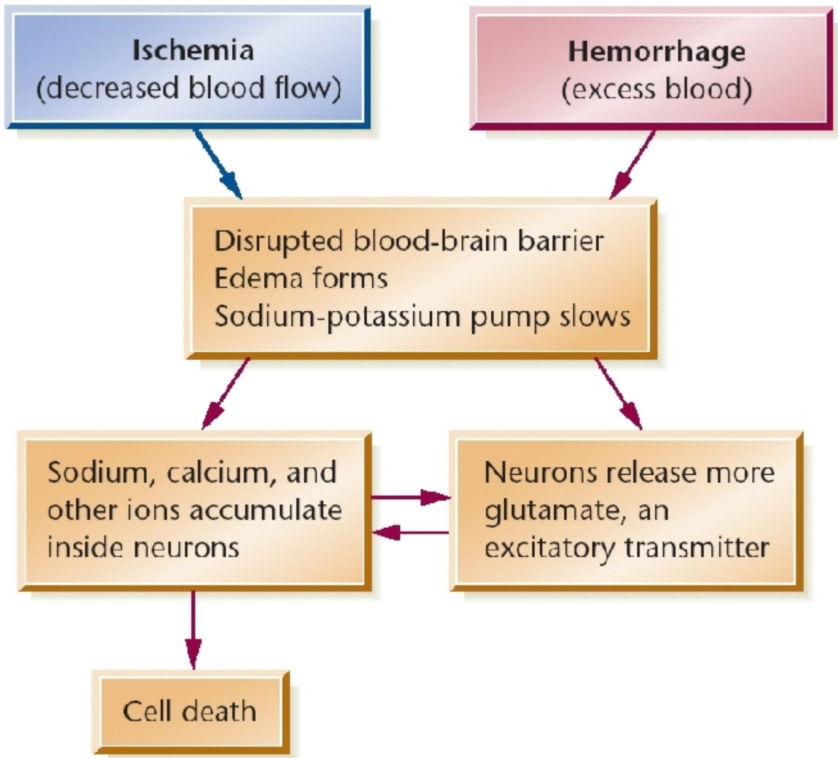


Figure 5.20, p127

4. – Some Contributions to human protections (3)

4.3. – Role of Fracture mechanics in Life Prediction and Quality Control of Medical Implants (1)

The fundamental tenet of Substitutive Medicine :

➔Beyond a certain stage of failure, it is more effective to remove or replace a malfunctioning organ than to seek in vain to cure it.

➔ Functional disabilities due to destruction or wear of body parts can be addressed in 2 ways :
* implantation of prosthetic device
* transplantation of natural organs.

Biomaterials	
Co-Cr alloys	Hydroxyapatite
Stainless steel	Alumina
Titanium, Nitinol Zirconium	Bioglasses Tricalciumphosphate
Niobium	Carbon
Tantalum	Polymers
Gold	

Among 1.5 million of candidates, less than 20 materials and chemical compounds have been successfully incorporated into clinical devices.

Problem !

➔ Statistics :

* 20 million people in US have at least one medical implant.

* USD 100 billion spent annually on prostheses and artificial organ

* 20% of all surgeries are to replace failed devices.

Three Immediate Problems :

➔ New implant materials :
* bone-like materials to prevent stress shielding;
* heart valve materials to prevent thrombosis.

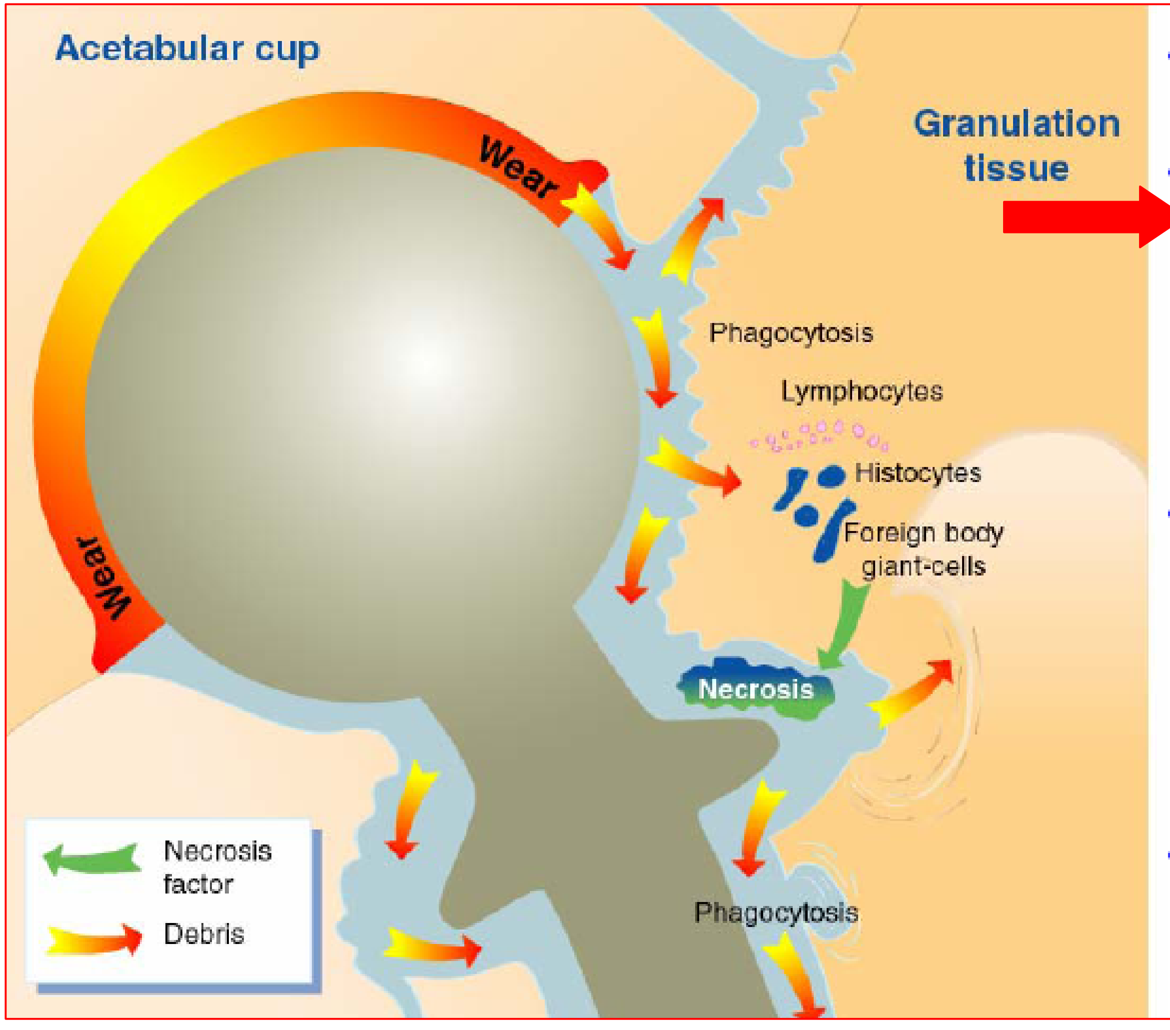
➔ Improved implant/tissue interfaces :
* as vast variety of devices fail due to interface failure.

➔ Lifetime prediction for medical devices.

4. – Some Contributions to human protections (3)

4.3. – Role of Fracture mechanics in Life Prediction and Quality Control of Medical Implants (2)

Total Hip Replacement - Osteolysis



- We take about one million steps a year
- As years pass, strong shock waves caused by walking, running & climbing erode cushioning between ball & socket at top of leg
- Soon, bone grinding on bone causes osteoarthritis, a condition that brings crippling pain and slows everything we do
- What's the answer? For more than 250,000 Americans a year: hip replacement surgery

4. – Some Contributions to human protections (4)

4.3. – Role of Fracture mechanics in Life Prediction and Quality Control of Medical Implants (3)

Mechanical Heart Valve Prostheses

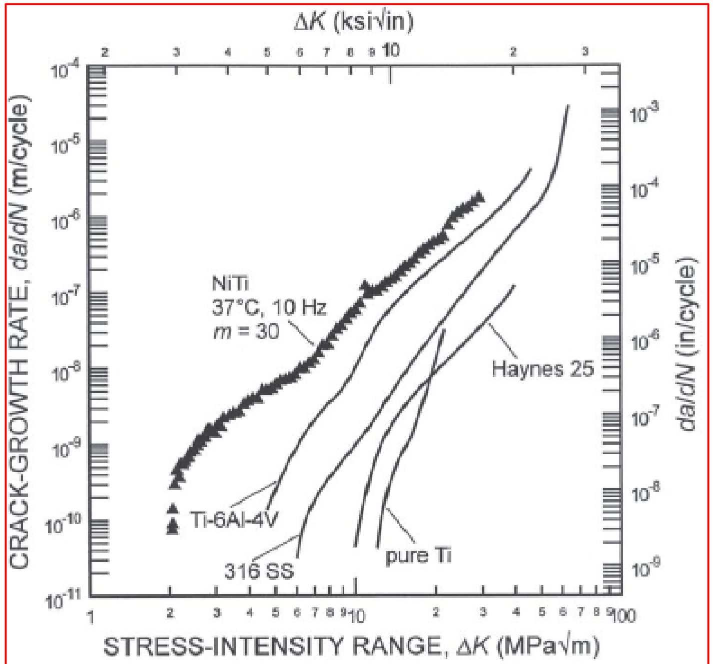
- In the aftermath of the Shiley valve problems, the trend has been away from metallic valves towards pyrolytic carbon valves
- with respect to fracture toughness, pyrolytic carbon is more than an order of magnitude more brittle than Ti or Co-Cr alloys
- hence special care must be taken in design and life-prediction procedures to prevent *in vivo* fractures

Prosthetic material	Young's modulus	Strength	Fracture toughness	Fatigue threshold
	(GPa)	(MPa)	(MPa √m)	(MPa √m)
Pyrolytic carbon	27 - 31	350 - 530	1 - 2	~0.7 - 2
Co-Cr (Haynes 25) alloy	209	450 - 1000	~60	4.5 - 10
Ti-6Al-4V alloy	115	925 - 1000	60 - 80	~3 - 4
Stainless steel (316L)	210	250 - 560	>100	~6 - 8
Nitinol (Ni-Ti) alloy	55 - 90	200 - 1200	35 - 50	~2

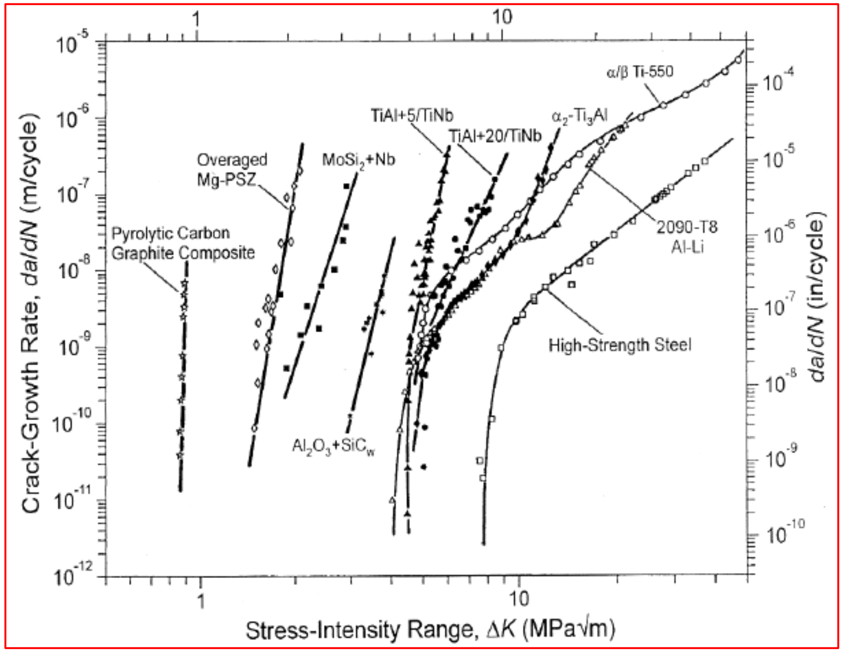
4. – Some Contributions to human protections (5)

4.3. – Role of Fracture mechanics in Life Prediction and Quality Control of Medical Implants (4)

Comparison of Metallic Implant Materials



$\Delta K = Q\,\Delta\sigma\,(\pi a)^{½}$



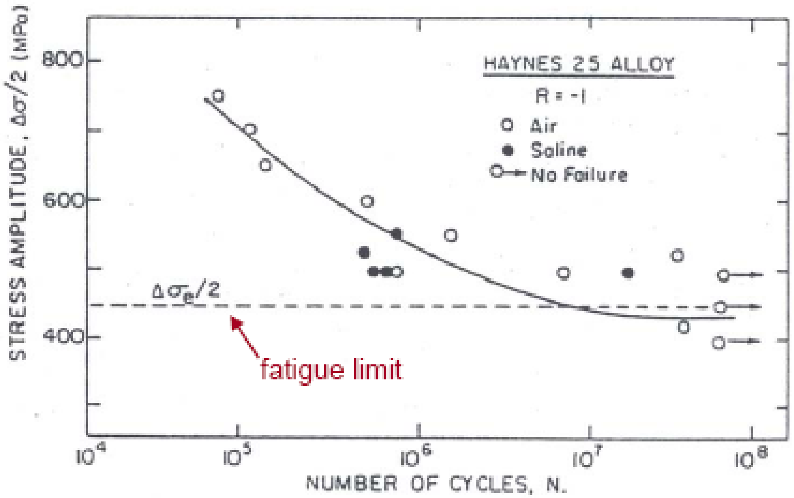
- interestingly, Nitinol is invariably used in the superelastic austenitic condition, which is the worst microstructure for fatigue resistance
- for devices such as stents and heart valves, fatigue can be the limiting damage mechanism
- of the typical materials used (316 SS, Co-Cr, Ti, Ti-6Al-4V and NiTi), Nitinol has the worst fatigue-crack growth properties

….and pyrolytic carbon is even the worse !!!

4. – Some Contributions to human protections (6)

4.3. – Role of Fracture mechanics in Life Prediction and Quality Control of Medical Implants (6)

Stress-Strain/Life (S-N) Analysis



- stress-life data represents the total lifetime as a function of stress amplitude
- depending upon the loading, data must be measured, or converted, to reflect role of mean stress (σ_m):

$$\frac{\Delta\sigma_R}{2} = \frac{\Delta\sigma_{R=-1}}{2}\left[1 - \frac{\sigma_m}{\sigma_{UTS}}\right]$$

- identify limiting failure mechanism(s)
- define critical location(s)
- estimate worse-case *in vivo* loading (e.g., from pulse duplicator studies)
- compute worse-case *in vivo* stresses (e.g., from numerical analysis)
- measure residual stresses in device material (e.g., by x-ray diffraction)
- determine stress-life (*S*-*N*) data under simulated physiological conditions
- estimate safe life as a function of worse-case stresses

4. – Some Contributions to human protections (7)

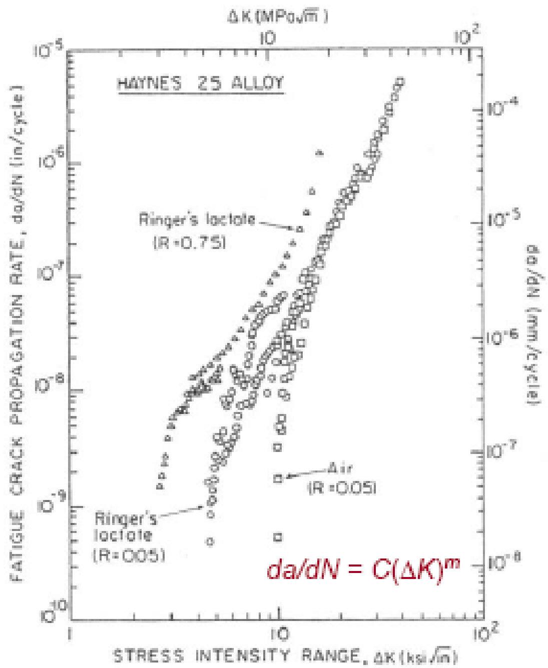
4.3. – Role of Fracture mechanics in Life Prediction and Quality Control of Medical Implants (7)

Procedures for Damage-Tolerant Analysis

- identify limiting failure mechanism(s)
- define critical location(s)
- estimate worse-case *in vivo* loading
- compute worse-case *in vivo* stresses
- measure residual stresses
- compute of stress-intensity factors K for worse-case flaws in critical locations
- measure crack velocity-stress intensity (v-K) relationships *in vitro*
- determine critical (largest) defect size to cause final failure (*e.g.*, defined by the fracture toughness, K_{Ic})
- compute lifetimes as a function of initial flaw size
- calculate initial flaw size that can yield an acceptable life – *the required detectable flaw size*
- design of a non-destructive testing procedure to detect such flaws in every device - *this provides the basis for Quality Control of the device*

$$K = Q\,\sigma\,(\pi a)^{1/2}$$

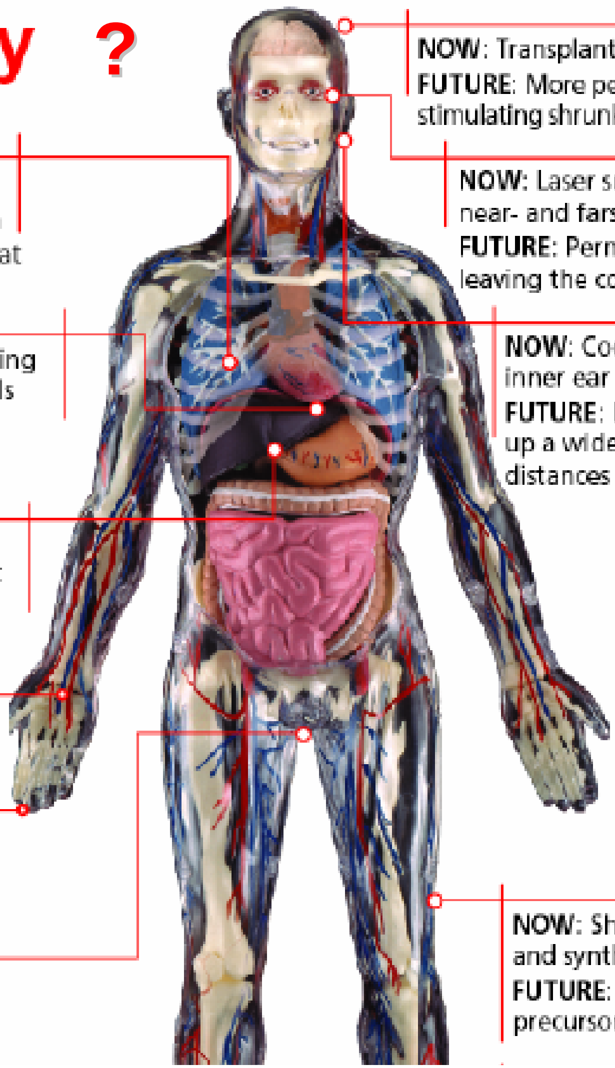
where K is the stress intensity
σ is the *total* in-service stress
a is the crack size
Q is a geometry factor (of order unity)



4. – Some Contributions to human protections (8)

4.3. – Role of Fracture mechanics in Life Prediction and Quality Control of Medical Implants

Can I Replace My Body ?



BREAST

NOW: Breasts are reconstructed with saline sacs or with living tissue, using fat and muscle from the back, buttocks or abdomen

FUTURE: Breasts may be grown in the lab from a patientís own fat cells and infused back through keyhole slits in the chest

HEART

NOW: Bypasses, angioplasty and transplants to keep blood flowing to the heart muscle. Use gene therapy to grow new blood vessels

FUTURE: Growing functional patches of heart muscle or coaxing existing heart-muscle cells to repair themselves

ORGANS

NOW: Small slivers of liver tissue can be grown in the lab from one of the many types of liver cells; not yet ready for transplant

FUTURE: Heart, liver, kidneys grown from stem cells *in vitro* and transplanted into the body

NERVES

NOW: Lab grown from pig cells and synthetic-polymer matrix

FUTURE: Regenerated from stem or precursor cells in the body

LIMBS

NOW: Prosthetics wired to peripheral nervous system

FUTURE: Prosthetics wired directly to motor portions of the brain to improve control and simulate the sensations of touch, pain, etc.

PENIS

NOW: Penile implants and medication to maintain erection. Surgery to reattach a severed penis; skin grafts to recover urinary, but not sexual, function if penis is not recovered

HAIR

NOW: Transplants, hair plugs and scalp grafts

FUTURE: More permanent approaches, perhaps by stimulating shrunken follicles with growth proteins

EYES

NOW: Laser surgery or implants to correct near- and farsightedness

FUTURE: Permanent lens implants to vision while leaving the cornea intact

EARS

NOW: Cochlear implants to replace damaged inner ear

FUTURE: Implants that can be adjusted to pick up a wider range of frequencies at longer distances

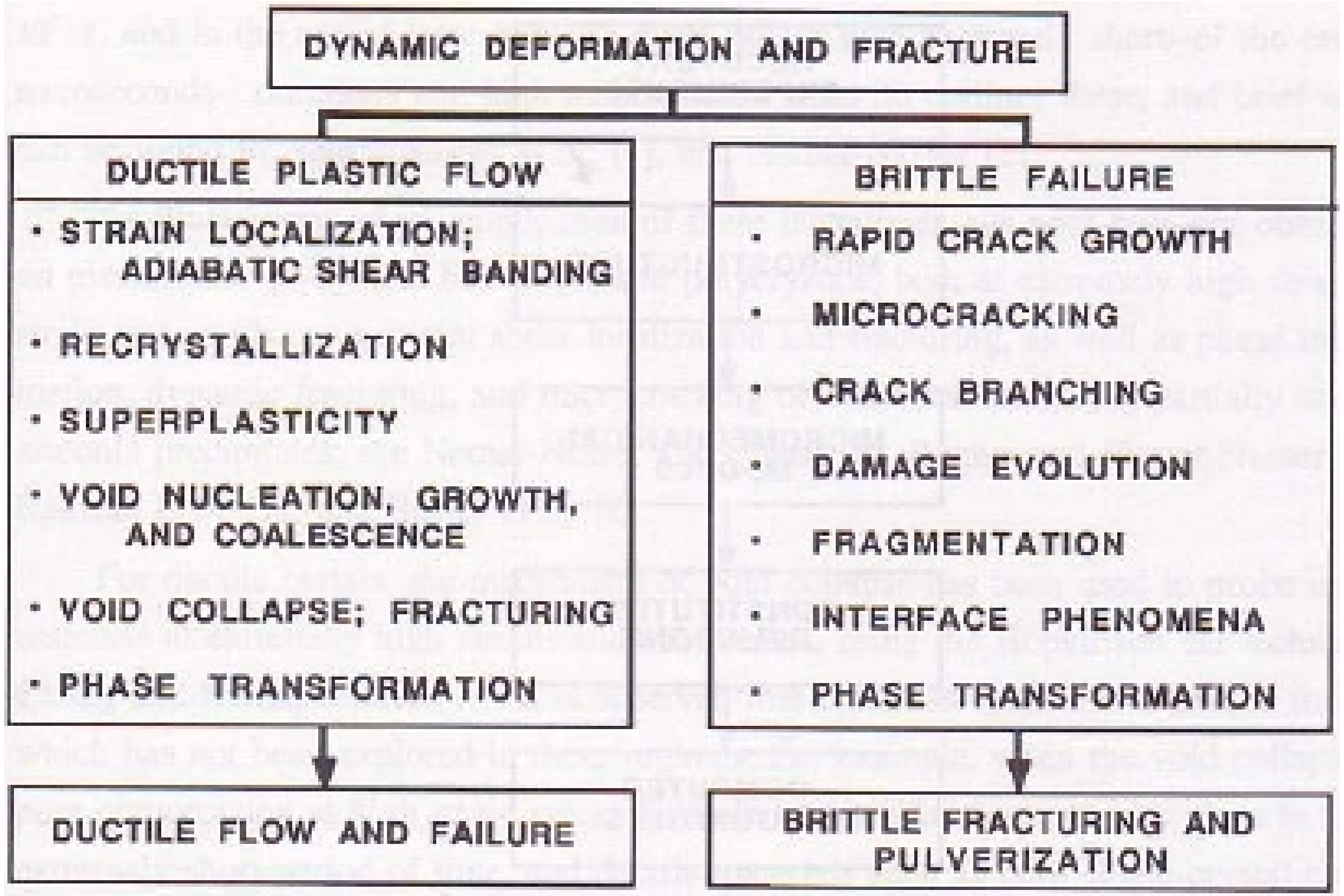
SKIN

NOW: Sheets grown in the lab from human and synthetic-polymer matrix

FUTURE: Grown by the body from stem or precursor cells and growth factors

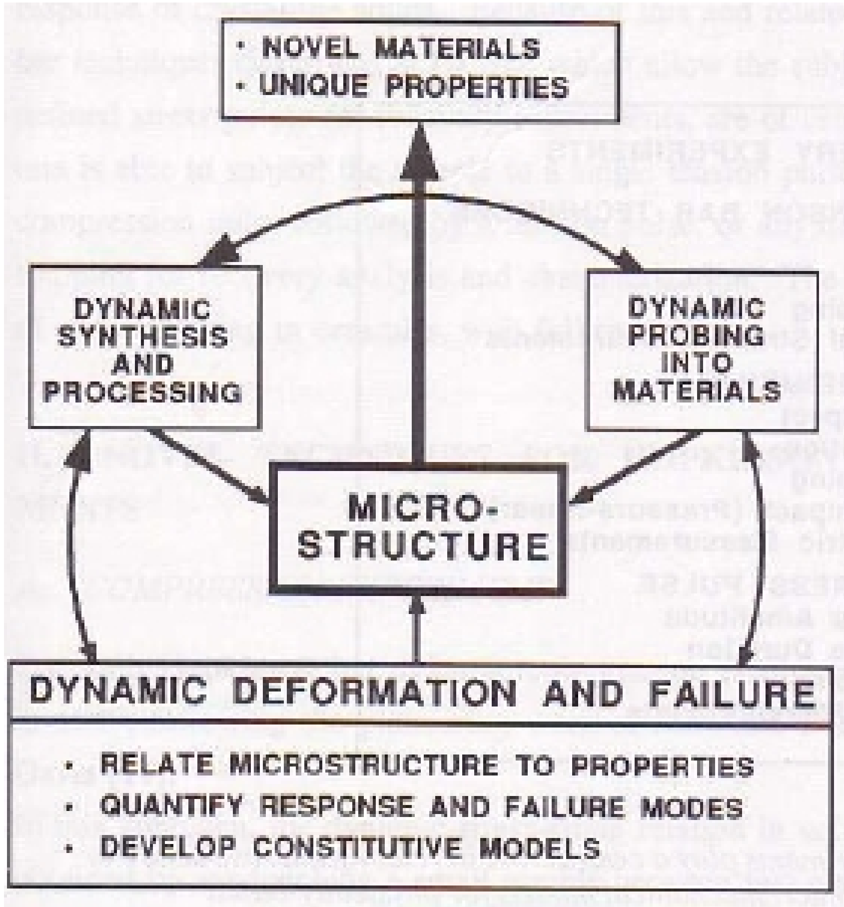
5. – CONCLUSIONS : - Trends of Research on Dynamic Plasticity and Dynamic Fracture (1)

5.1. – Major Issues in Dynamic Deformation and Failure Modes of Ductile and Brittle Materials



5. – Trends of Research on Dynamic Plasticity and Dynamic Fracture (2)

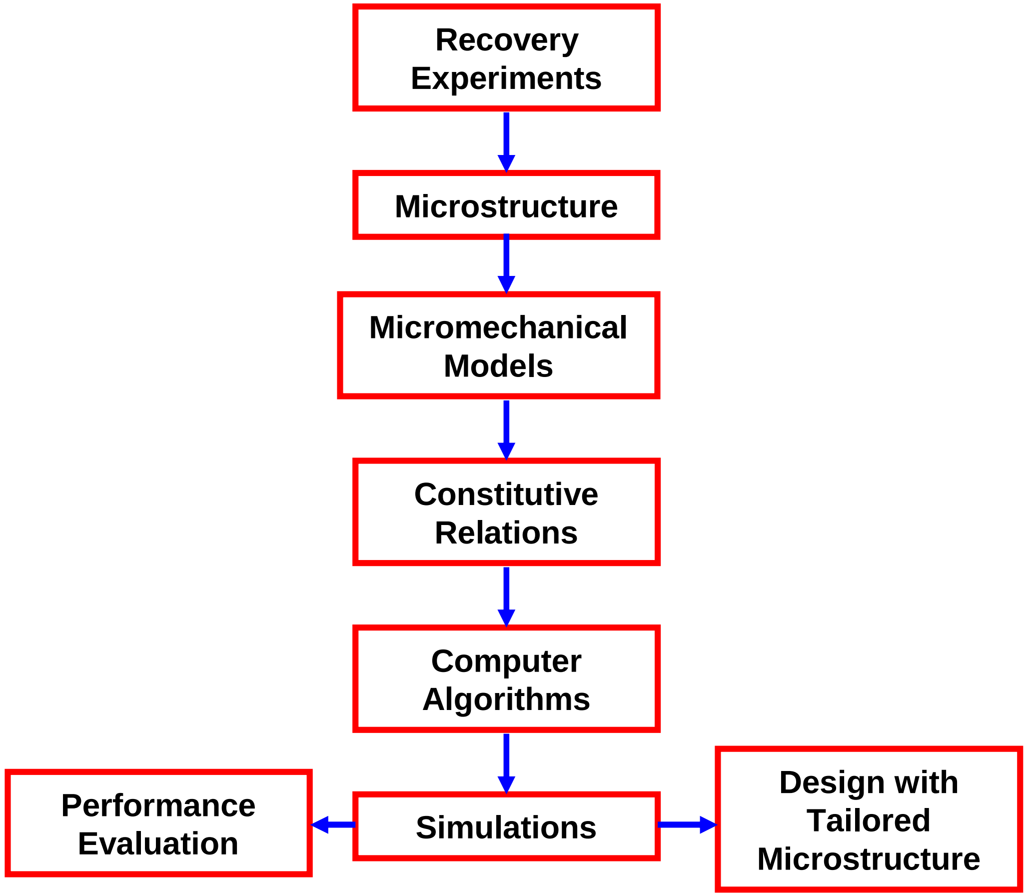
5.2. – Dynamic Processing of New Materials



5. – Trends of Research on Dynamic Plasticity and Dynamic Fracture (3)

5.3. – Dynamic Recovery Experiments

To Include Scale Effects Studies : Macro-Meso-Micro-Nano-Scales



DYNAMIC RECOVERY EXPERIMENTS

► **NOVEL SPLIT HOPKINSON BAR TECHNIQUES**
- Pulse-shaping
- Stress-Reversal
- Full Pulse Trapping
- Direct Multi-Axial Strain Measurements

► **PLATE IMPACT EXPERIMENTS**
- Normal Plate Impact
- Novel Configuration
- Full Pulse Trapping
- Oblique Plate Impact (Pressure-Shear)
- Full Interferometric Measurements

► **LASER-INDUCED STRESS PULSE**
- Very High Stress Amplitude
- Very Short Pulse Duration
- Full Pulse Trapping
- Time-Resolved Measurements

6. – FUTURES

6.1. – Synergy of Engineering Sciences and Nature (1)

A new approach of Biomimicking and Bioduplication studies
applied to Static and Impact Strength of Sea Shells.
Example of previous results on Abalone Toughning Mechanism

2 KEYWORDS

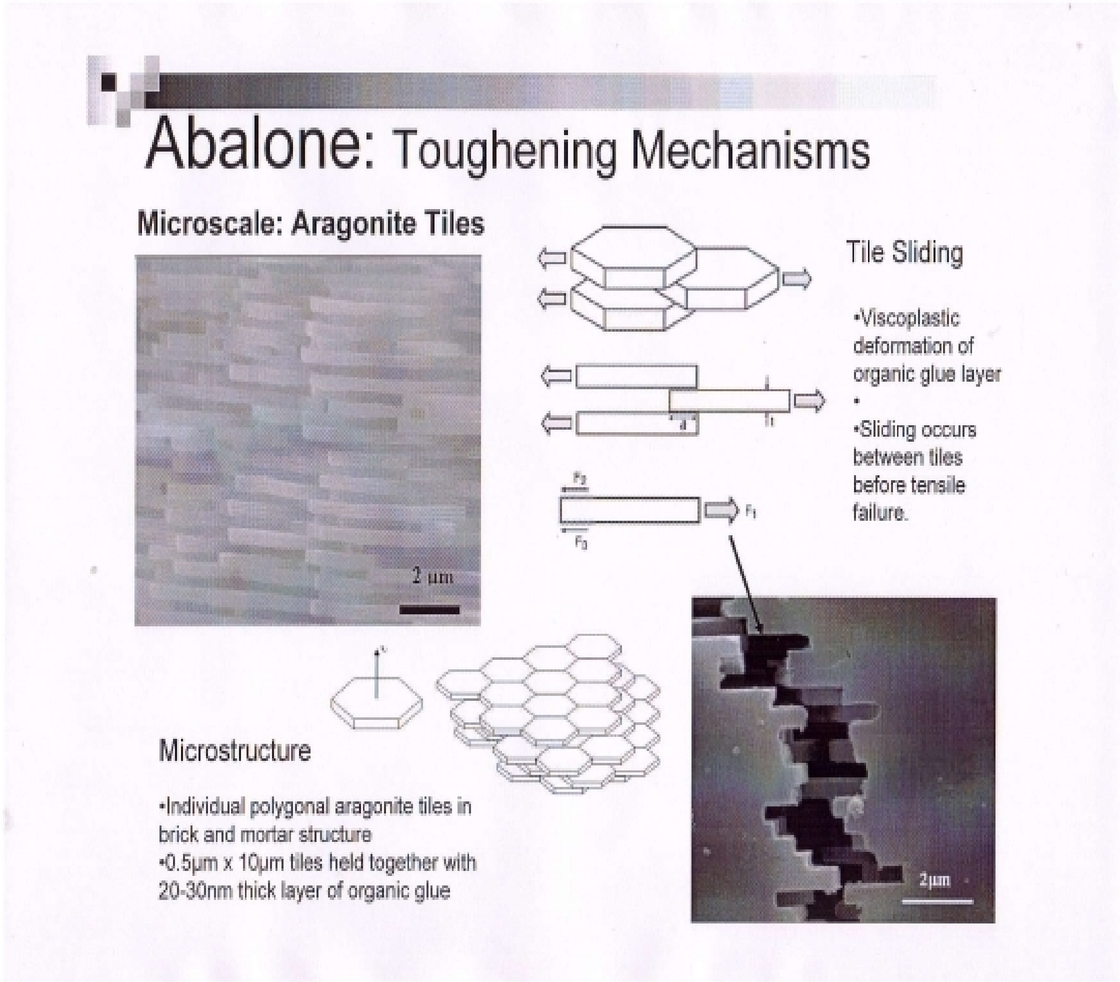
•(1) – **Biomimicking** studies which approach is the understanding of biological systems and the application of such concept to synthetic materials using our knowledge of current technology. In more simple terms, our goal is: "Learning from nature to make new materials". Particularly, the nature's advantages are based on "time" and "evolution" to create sophisticated and strong composites. Basic inorganic materials in nature are very weak on their own but can form high strength composites.

(2) – **Bioduplication** which is the concept of generating new technologies from the understanding of the existing processes in the nature through knowledge of genetic engineering. These new technologies shall be used to produce an entire class of new materials.

6. – FUTURES

6.1. – Synergy of Engineering Sciences and Nature (2)

Previous results on :



6.1. – Synergy of Engineering Sciences and Nature (3)

Mechanical Analysis: Giant Clam

Compression

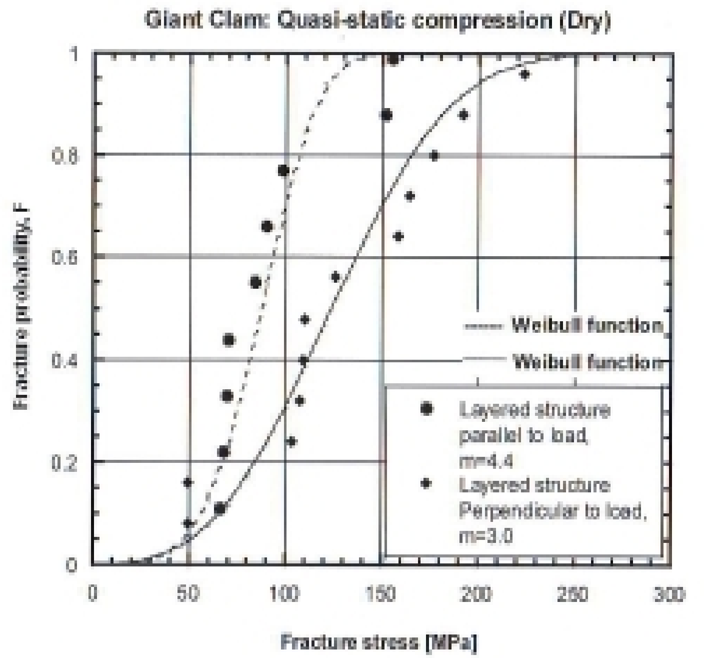
•Samples were compressed parallel and perpendicular to layered structure

Weibull analysis [2]

$$F(V) = 1 - \exp\left[-\left(\frac{\sigma}{\sigma_0}\right)^m\right]$$

- F(V) is the failure probability,
- m and σ_0 are experimental parameters
- σ is the maximum strength

S-shaped distribution for failure predictions.



[2] Weibull, W., *Ingenioersvetenskapsakad. Handl.*, 1939,151,1.

6.1. – Synergy of Engineering Sciences and Nature (4)

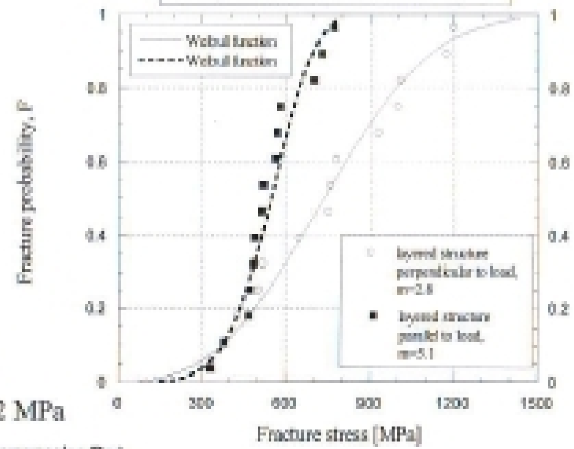
Comparison

DYNAMIC COMPRESSION

Abalone

Parallel σ = 534 MPa

Perpendicular σ =746 MPa



Testing Machine: Momentum-trapped Split Hopkinson Bar

High Strain Rate : 15~25 x10^3 GPa/s

<u>50% Fracture probability Stress (MPa)</u>

Conch:

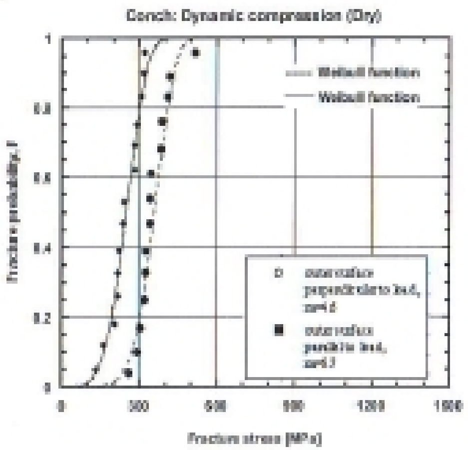
Parallel σ = 360 MPa

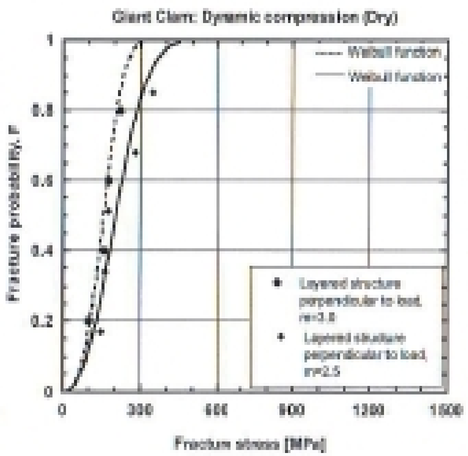
Perpendicular σ = 225 MPa

Giant Clam:

Parallel σ = 160 MPa

Perpendicular σ = 202 MPa



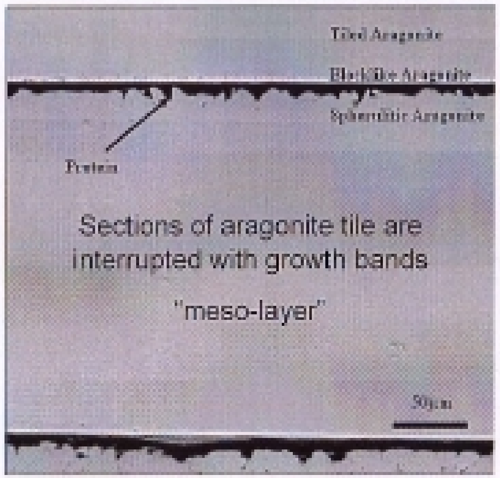


- Again abalone shows over twice the mechanical strength of compared shells
-
- Conch and giant clam have relatively similar strengths regardless of micro-organization

6.1. – Synergy of Engineering Sciences and Nature (5)

Abalone: Toughening Mechanisms

Mesolayer: Growth Bands

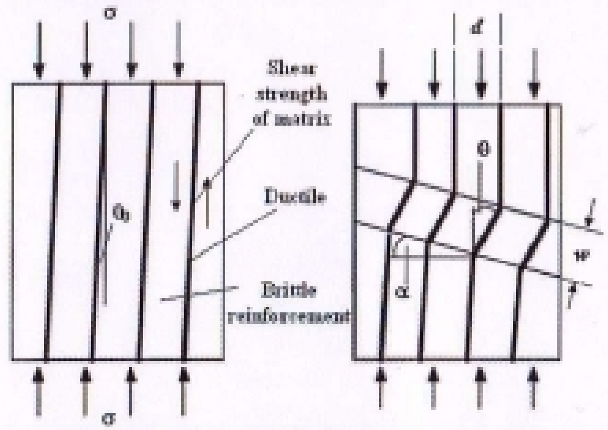


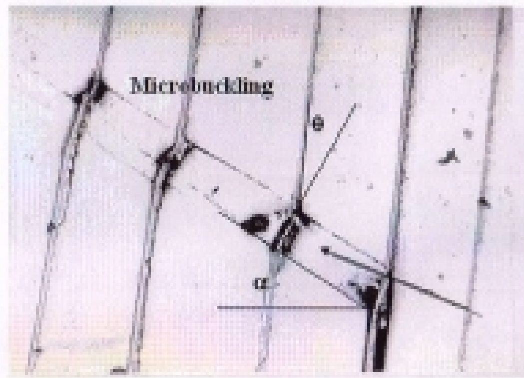
$$\frac{w}{d} = \frac{\pi}{4}\left(\frac{2\tau_y}{CE}\right)^{-1/3}$$

Budiansky Equation [1]:
Ratio of thicknesses of kink bands and spacing between reinforcement units (w/d)

- E is the Young's modulus of the fibers
- C is their volume fraction.

Micro-buckling at Growth Bands



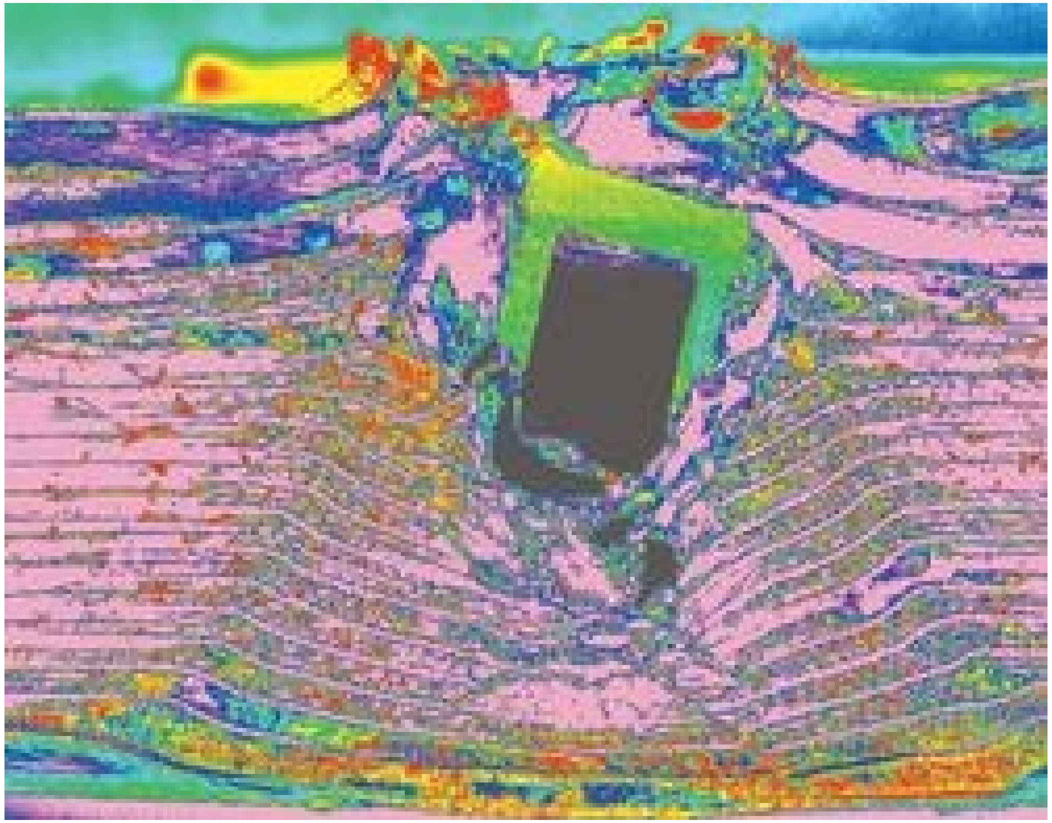


[1] Budiansky, B., *Comput. Struct.*, 1983,16,3.

6.1. – Synergy of Engineering Sciences and Nature (6)

Exemple of An approach of Biomimicking
of Abalone bio-materials
and Bioduplication to manufacture new materials

Biomimicking of
Abalone shell



Bioduplication of abalone process
to form new type of strong and
light weight metallic metarials.